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BRICKS: AN EXCELLENT BUILDING MATERIAL FOR RECYCLING WASTES – A REVIEW

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ABSTRACT
Brick is one of the most common masonry units as a building material due to its properties. Many attempts have been made to incorporate wastes into the production of bricks, for examples, rubber, limestone dust, wood sawdust, processed waste tea, fly ash, polystyrene and sludge. Recycling such wastes by incorporating them into building materials is a practical solution for pollution problem. This paper reviews the recycling of different wastes into fired clay bricks. A wide range of successfully recycled materials and their effects on the physical and mechanical properties of bricks have been discussed. Most manufactured bricks with different types of waste have shown positive effects on the properties of fired clay bricks.

KEY WORDS
Fired clay bricks; Waste management; Waste recycling; Building materials.

1. INTRODUCTION

Brick is one of the oldest manufactured building materials in the world. As early as 14,000 BC, hand-moulded and sun-dried clay bricks were found in the lower layers of Nile deposits in the Egypt. Clay was also ancient Mesopotamia's most important raw material and most buildings during that time were made of clay bricks. The earliest use of bricks recorded was the ancient city of Ur (modern Iraq) that was built with mud bricks around 4,000 BC and the early walls of Jericho around 8,000 BC. Starting from 5,000 BC, the knowledge of preserving clay bricks by firing has been documented. The fired bricks were further developed as archaeological traces discovered in early civilisations, such as the Euphrates, the Tigris and the Indus that used both fired and unfired bricks. The Romans used the fired bricks and were responsible for their introduction and use in England. However, the brick making craft declined following the departure of the Romans from Britain in 412 AD and was only revived later by Flemish brick makers. The development of different types of bricks continued in most countries in the world and bricks were part of the cargo of the First Fleet to Australia, along with brick moulds and a skilled brick maker. Bricks have continuously been used by most cultures throughout the ages for buildings due to their outstanding physical and engineering properties (Lynch, 1994; Christine, 2004).

Brick is one of the most demanding masonry units. It has the widest range of products, with its unlimited assortment of patterns, textures and colours. In 1996, the industry produced 300 million bricks in Victoria, which were about 55% of the potential production of the facilities available. The export markets included Japan, New Zealand, the Middle East and other Asian countries. This is equivalent to an annual turnover of 130 million dollars (EPAV, 1998). Brick is durable and has developed with time. It remains highly competitive, technically and economically, with other systems of structure and field. The main raw material for bricks is clay 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 (Hendry and Khalaf, 2001). 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.

Clay bricks are very durable, fire resistant, and require very little maintenance. The principal properties of bricks that make them superior building units are their strength, fire resistance, durability, beauty and satisfactory bond and performance with mortar (Lynch, 1994; Hendry and Khalaf, 2001). Additionally, bricks do not cause indoor air quality problems. The thermal mass effect of brick masonry can be a useful component for fuel-saving, natural heating and cooling strategies such as solar heating and night-time cooling. They have moderate insulating properties, which make brick houses cooler in summer and warmer in winter, compared to houses built with other construction materials. Clay bricks are also non-combustible and poor conductors (Mamlouk and Zaniewski, 2006).

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Clays as raw material for clay bricks are most valued due to their ceramic characteristics (Lynch, 1994; Christine, 2004). Clays are derived from the decomposition of rocks such as granite and pegmatite, and those used in the manufacture of brick are usually from alluvial or waterborne deposits. The presence of rock particles causes the clays to burn into bricks of varying colours and appearance. The important properties of clays that make them highly desirable as brick materials are the development of plasticity when mixed with water, and the hardening under the influence of fire, which drives off the water content (Marotta and Herubin, 1997). Normally, the physical nature of the raw materials controls the manufacturing methods. The overall process fundamentally consists of screening, grinding, washing and working the clay to the proper consistency for moulding into bricks, regardless of whether the process is done by hand or machine.

The volume of waste from daily activities, production and the industry continues to increase rapidly to meet the demands of the growing population. On top of that, the environmental regulations become more restrictive. Therefore, alternative methods to manage and utilise these wastes have to be determined. Environmentally friendly waste recycling has been one of the very important research fields for many decades. A popular trend by researchers has been to incorporate wastes into fired clay bricks to assist the production of normal and lightweight bricks. The utilisation of these wastes reduces the negative effects of their disposal. Many attempts have been made to incorporate waste in the production of bricks including rubber, limestone dust, wood sawdust, processed waste tea, fly ash, polystyrene and sludge. Recycling the wastes by incorporating them into building materials is a practical solution to pollution problem. The utilisation of wastes in clay bricks usually has positive effects on the properties, although the decrease in performance in certain aspects has also been observed. The positive effects such as lightweight bricks with improved shrinkage, porosity, thermal properties and strength can be obtained by incorporating the recycled wastes. Most importantly, the high temperature in clay brick firing process allows: (a) volatilisation of dangerous components, (b) changing the chemical characteristics of the materials, and (c) incorporation of potentially toxic components through fixation in the vitreous phase of the waste utilised (Vieira et al., 2006).

Lightweight bricks are lighter than the standard bricks. Lightweight bricks are generally preferred because they are easier to handle and thus their transportation costs are lower. The development of lightweight bricks allows brick manufacturers to reduce the total clay content through the introduction of holes or incorporation of combustible organic waste particles that reduce the mass of the brick while maintaining the required properties. Moreover, lower energy consumption during firing from the contribution of the high calorific value provided by many types of waste has also been studied (Dondi et al., 1997a and 1997b).

2. OVERVIEW OF RECYCLED WASTES IN CLAY BRICKS

Due to the demand of bricks as building materials, many researchers have investigated the potential wastes that can be recycled or incorporated into fired clay bricks. Owing to the flexibility of the brick composition (Lynch, 1994; Dondi et al., 1997a; Christine, 2004), different types of waste have been successfully incorporated into fired clay bricks by previous researchers, even in high percentages. From the literature reviews related to the inclusion of waste materials, they apparently vary from the most commonly used wastes such as the various types of fly ash and sludge, to sawdust, kraft pulp residues, paper, polystyrene, processed waste tea, tobacco, grass, spent grains, glass windshields, PVB-foils, label papers, phosphogypsume (waste used by phosphoric acid plants), boron concentrator and cigarette butts. The utilisation of these wastes will help to reduce the negative effects of their disposal. However, the potential wastes can only be recycled if the properties and the environmental pollutant of the new manufactured brick meet the specific requirements and comply with the relevant standards. In this review, wastes used in bricks have been divided into three main categories, which are sludge, fly ash and other wastes.

2.1 Sludge

This category includes sludge from sewage treatment plant, sludge from paper industry, tannery sludge, iron and arsenic sludge and sludge ash. Some studies were reviewed by Show and Tay (1992) on the potential of sludge applications. It is reported that Tay (1984; 1985; 1987) used municipal wastewater sludge mixed with clay to produce bricks. The percentages by mass of dried municipal sludge used ranged from 10% to 40% with 1080 °C as the firing temperature. The shrinkage after firing and water absorption value increased with the increased amount of sludge. An uneven surface texture to the finished product was observed due to the organic substances in the sludge. Tay (1987) also utilised pulverised sludge ash, which was collected after sludge incineration at 600 °C. The addition of 10% to 50% pulverised sludge ash was carried out and it was concluded that 50% by mass was the maximum to produce a good bonding brick. The water absorption increased with the amount of sludge ash incorporated. The strength obtained from the test was as high as normal clay bricks with 10% of sludge ash and much better than the clay with dried sludge. The maximum percentages of dried municipal sludge and municipal sludge ash that could be mixed with clay for brick making were 40% and

50% by mass, respectively. Leaching tests conducted on the sludge product also showed positive results with no sign of potential contamination problems for similar applications. Another sludge that was recycled by Tay et al. (2001) was the industrial sludge. Bricks were manufactured from industrial sludge from 30% up to 100%. The firing temperature employed was 1050 °C. During the observation, cracks were prone to occur during the firing with 100% sludge and 90% sludge with 10% clay. The water absorption limit of 7% was verified for bricks of all mixtures except for bricks that contained 50% clay. Tay et al. (2002) also reported that "biobricks" were manufactured by mixing clay and shale with sludge with a solid content ranging from 15% to 25%.

According to Dondi et al. (1997a) in their review of previous research, the waste from sewage sludge treatment plants was used in several studies. The waste was high in organic content, varying from 10% to 20% by mass (Mesaros, 1989). Validation on the specific amount of calorific value was hard to verify but an estimated calorific value of 10,000 kJ/kg of dry fraction was estimated to save from 10% to 40% and could be higher (Mesaros, 1989). According to Dondi et al. (1997a), a positive contribution can be achieved from less than 2% until 25% to 30% (Allemen, 1987; Allemen, 1989) from the waste added to the clay brick. A higher amount of sludge could lead to negative results to the manufactured brick (Mesaros, 1989; Brosnan and Hochlreitner, 1992). Similarly, Liew et al. (2004) also concluded in their study that the maximum percentage of sludge should not be more than 30% by mass due to its fragility and that the addition of 20% sludge would maintain the functional characteristics of the brick. The main advantages were related to the amount of energy saved and the environmentally friendly way to dispose the sludge waste (Slim and Wakefield, 1991; Churchill, 1994; Liew et al. 2004). Increased plasticity due to the fibrous nature of the waste added makes brick moulding easier (Allemen, 1987; Mesaros, 1989). However, the dry shrinkage results obtained were not in agreement as some cases seemed to involve significant increases in shrinkage with crack formation during the drying process (Mesaros, 1989; Allemen, 1989; Liew et al. 2004) while others involved less dry shrinkage and drying sensitivity (Brosnan and Hochlreitner, 1992). In other articles reviewed by Dondi et al. (1997a) that utilised sludge from treatment plants revealed an increased percentage of water absorption and firing shrinkage and a decrease in dry density, for example 30% of sewage sludge reduced the dry density by 15% (Tay, 1987). The negative aspects of the firing process included the unpleasant odour emitted (Brosnan and Hochlreitner, 1992), efflorescence effect (Brosnan and Hochlreitner, 1992) and black coring to the final product. These findings were also supported by current research as Liew et al. (2004) found that high amount of sludge added into the clay brick increased the drying shrinkage but decreased the firing shrinkage. The water absorption value increased up to 37% compared to the control brick (23.6%) and the compressive strength decreased to 2 N/mm^2 against 15.8 N/mm^2 for the control brick, which was obtained with the addition of 40% sludge. Gases including steam and CO_2 were emitted during the firing process due to the combustion of the organic content in the sludge. At the same time, cracking and bloating were also observed at the fired brick. The cross sections of the brick also revealed black coring attributed by the organic matter. A significant growth of pores was also identified and contributed to the mechanical properties that were achieved with the inclusion of 10% to 40% sludge. Because of all the weaknesses, the bricks produced in this study were only appropriate for the use as common bricks because of the poor exterior surface.

The sludge from the wastewater treatment process of the paper industry was also reviewed by Dondi et al. (1997a). With 20% by mass of dry weight of organic substances (Zani et al., 1990) and a calorific value around 8,400 kJ/kg, the mass of the brick was reduced to more than 50% by mass (Zani et al., 1990) due to the large organic content in the waste. Dondi et al. (1997a) also stated that studies were carried out by incorporating not more than 10% by mass of the dried sludge to the clay bodies. It was concluded that the optimum range was from 3% to 8% by mass (Zani et al., 1990). Incorporation of the sludge into the body of the brick increased the dry shrinkage and the required water content for the manufactured brick. There was no significant problems occurred during the moulding and the drying process (Zani et al., 1990) even though some studies revealed that the fibrous nature of the waste led to shaping and moulding difficulties and also affected the amount of waste that should be incorporated (Kutassy, 1982). A low addition of this waste did not affect the brick properties extensively. However, slight increase in water absorption, insignificant reduction in the mechanical strength and deterioration of the fired bricks were some of the effects of adding the waste (Kutassy, 1982). Fuel savings varied from very low values (Kutassy, 1982; Zani et al., 1990) up to about 18% (Zani et al., 1990) with sludge incorporation. However, different conclusions were made in the studies conducted. It was claimed that the waste offered economic benefits while maintaining the properties of the manufactured bricks (Zani et al., 1990). In addition, sludge waste from the paper industry was successfully recycled by a number of Italian brick manufacturers.

Basegio et al. (2002) discussed the utilisation of tannery sludge as a raw material for clay products. Tannery sludge and clay were mixed together with different proportions (9%, 10%, 20% and 30%) as the raw materials in their study. The brick was fired at 1000 °C, 1100 °C and 1180 °C and was shaped in the mould using the hydraulic pressing method. Specific testing for clay bricks was conducted on the samples to determine the mechanical properties. Water absorption increased with the increase in percentage of sludge. With an increase in firing temperature, the water absorption and porosity considerably decreased. A higher firing temperature and a lower amount of sludge showed the greatest dry density. The maximum shrinkage occurred between 1100 °C and 1180 °C. Samples containing 30% sludge showed the lowest dry density and highest linear shrinkage. The bending strength increased with a higher firing temperature and lower sludge addition with a maximum of 25 MPa with 0% and 10% sludge at 1180 °C. Porosity also has an influence on the mechanical properties of the material. According to the Brazilian Standard, the results collected from the leaching test in this research showed that the main sludge contaminant, which was chromium, might had been immobilised in the finished clay product. However, 30% sludge was recommended as the raw material to prevent lead in the leachable waste. As for the gas emissions, the clay product did not immobilise the gas. Thus, sulphur, zinc and chlorine were detected during the test. However, the bricks application complied with the minimum requirements for the building industry and 10% tannery sludge was deemed a safe amount to be used with respect to the environmental characteristics of the product.

Rouf and Hossain (2003) used 5%, 15%, 25% and 50% of iron and arsenic sludge in clay bricks with firing temperatures of 950 °C, 1000 °C and 1050 °C. In this study, they claimed that 15% to 25% by mass with 15% to 18% optimum moisture content was the appropriate percentage of sludge mixture to be incorporated. The compressive strength test indicated that the strength of the brick depended significantly on the amount of sludge in the brick and the firing temperature. The results showed that 15% by mass was the optimum amount of sludge with a 1000 °C firing temperature. However, the strength of the brick can be as high as normal clay bricks with up to 25% sludge at a firing temperature of 1050 °C. The specific surface area of the corresponding mixture, the particle fineness and water requirement increased proportionally to the amount of sludge added to the clay. However, it decreased the plastic behaviour of the clay. The water absorption of the brick also decreased when the amount of sludge was reduced with an increase in firing temperature. The quantity of sludge added to the mixture is inversely proportionate to the bulk dry density. With the right amount of moisture content in the mixture, any deformation or uneven surface did not occur on the manufactured samples at all firing temperatures. The leaching of arsenic resulting from the TCLP test was far below the regulated TCLP limits and the quantity of metal sludge was less than dried sludge. The study concluded that the proportion of sludge and firing temperature were the two main factors in controlling the shrinkage in the firing process and at the same time for producing a good quality brick. Sludge proportions of 15% to 25% sludge and firing at 1000 °C to 1050 °C were suggested by Rouf and Hossain (2003) to produce good quality sludge bricks. They demonstrated that the original characteristics of normal clay bricks were retained with the addition of 25% sludge and the arsenic leaching was significantly reduced when the bricks were burnt at a high temperature.

2.2 Fly ash

Several researchers have tried to recycle fly ash to bricks. According to Dondi et al. (1997b), the clay and fly ash ratio used in previous research ranged from 10:1 to less than 1:1. Nevertheless, most recent studies have used 40% to 100% fly ash (Pimraksa et al., 2001; Lingling et al., 2005; Kayali, 2005 and Lin, 2006). One of the advantages of using fly ash is that the waste saves the firing energy as its calorific value ranges from 1,470 to 11,760 kJ/kg. Kayali (2005) and Pimraksa et al. (2001) have reported a reduction of density from 4% to 28% with better results on other properties. The other brick properties tested showed an improvement in plasticity, drying and decreased firing shrinkage and crack formation (Sajbulatow et al., 1980; Srbek, 1982; Anderson and Jackson, 1983; Pimraksa et al., 2001; Lingling et al., 2005; Lin, 2006). However, these properties depend on the quantities of fly ash added and the use of different compositions in the brick (Anderson and Jackson 1983; Usai, 1985; Pavlola, 1996; Pimraksa et al., 2001; Lingling et al., 2005; Kayali, 2005 and Lin, 2006). Different particle size distribution of fly ash also has an effect on the properties. Fine fly ash has been proved to be better than coarse fly ash (Anderson and Jackson, 1983; Pimraksa et al., 2001) as the fine fly ash improves the dry density, firing shrinkage and mechanical properties (Pimraksa et al., 2001; Lin, 2006). Moreover, the addition of fly ash also reduces efflorescence (Mortel and Distler, 1991). Besides, even the addition of wet low quality fly ash also produces brick with high resistance to efflorescence and frost melting (Lingling et al., 2005).

Dondi et al. (1997b) concluded that the addition of 10% fly ash is favourable in terms of energy saving. Nevertheless, Lin (2006) recommended 40% of fly ash slag with 800 °C as the firing temperature to produce a good quality brick while saving energy usage in the manufacturing process. From an economic point of view, the results vary from very promising (Sajbulatow et al., 1980 Pimraksa et al., 2001; Kayali, 2005 and Lin, 2006), recommendable (Mortel and Distler, 1991; Anderson and Jackson, 1983; Srbek, 1982; Usai, 1985) to unconstructive (Anonymous, 1979).

2.3 Other wastes

Krebs and Mortel (1999) investigated the use of residue from brewery waste in bricks. The resulting lightweight bricks had improved porosity and thermal conductivities without affecting the mechanical strength. They also investigated various waste additives that had to be processed before it could be used for inclusion within the bricks such as windshield glass, PVB-foils and label papers. The main objective of these additives was to act as pore formers in the manufactured brick. A combination of pelletised old labels and fly ash obtained good results. There was no problem occurred during the manufacturing process. The utilised residues reduced the dry density while maintaining similar or achieving even higher compressive strength. Significant porosity growth was also observed with the burn out of the label pellets. The PVB-polymer, which was produced from windshield glass, also demonstrated positive results on the fired brick. Energy usage was reduced by recycling this pore forming agent inside the brick due to its high calorific value (28,260 kJ/kg), which contributed to the firing process. Hence, gas emissions have to be monitored as the combustion of PVB-polymer almost completely turned into CO_2 and H_2O. Crushed PVB-polymer additives conferred more positive results to the brick. The PVB-pellets improved the drying shrinkage of the green brick tremendously and increased the porosity of the bricks produced accordingly.

Waste of interest to Veiseh and Yousefi (2003) was polystyrene. The main objective of adding polystyrene foam to clay bricks was to reduce the dry density of the brick as well as to improve the thermal insulation properties. The firing temperature used was from 900 °C to 1050 °C with mixes containing 0.5%, 1%, 1.5% and 2% by mass of the added polystyrene foam. The results from this study demonstrated that although increasing the amount of polystyrene in the clay brick increased the water absorption properties. At the same time, it decreased the strength and dry density of the manufactured brick. Consequently, for the usage of the manufactured brick to be sufficient for load bearing purposes in accordance with the Iranian Standard, only 2% of polystyrene could be incorporated. Better compressive strength and lower water absorption were achieved using higher temperatures during the firing process. An improvement in thermal performance was also obtained with 1.5% recycled polystyrene compared to the ordinary bricks.

Another waste that can be utilised in clay bricks according to Demir et al. (2005) is kraft pulp production residues. Increasing the amounts of the waste has been incorporated in clay bricks by 0%, 2.5%, 5% and 10%. All samples were fired at 900 °C with another group was left unfired. The required water content and drying shrinkage increased with the increased amount of kraft pulp residue. 10% addition was not suitable due to the increased drying shrinkage. However, the addition of up to 5% residue increased the dry bending strength, which was useful for handling purposes of the unfired bricks. The organic nature of the waste supplemented the heat input of the kiln. It can also be effectively used in pore forming for the clay brick at up to 5% addition levels. The compressive strength value decreased with the addition of the waste but still complied with the standards.

Processed waste tea (PWT) was another waste that was reported by Demir (2006) to be used in clay bricks. Varying percentages of waste – 0%, 2.5% and 5%, by mass were incorporated in the clay bricks. The potential of PWT in the unfired and fired clay body was investigated due to the organic nature of PWT. The improved compressive strength results if compared to the control samples indicated that the pore forming of PWT in the fired body and the binding in the unfired body had a significant potential in both conditions of clay brick. The firing temperature used was 900 °C. It was observed that with higher amounts of PWT, the shrinkage, water absorption, compressive strength and porosity were increased but the dry density was decreased. The organic characteristics of PWT supplemented the heat input of the furnace and acted as an organic kind of pore forming additive. The use of the waste improved the physical and mechanical properties of the bricks and also one of the environmentally friendly alternatives in brick manufacturing.

Furthermore, Demir (2008) also utilised various organic residues such as sawdust, tobacco residues and grass from industrial and agricultural waste. These residue materials have long cellulose fibres. Differing amounts of waste were incorporated in the clay bricks – 0%, 2.5%, 5% and 10%. All samples were fired at 900 °C while one batch was left unfired. According to Demir (2008), while maintaining acceptable mechanical properties, these wastes could act as an organic pore forming agent in clay bricks and increased the porosity, thus improved the insulation properties. Adding organic residues increased the plasticity and thus increased the water content required. A residue addition of 10% was not suitable as the drying shrinkage increased excessively due to the effect of cellulose fibres. The dry strength of the brick increased but the compressive strength of the fired samples reduced due to the addition of the residues. Nevertheless, the compressive strength values still complied with the Turkish Standards. 5% of the residue addition was effective for pore forming but further additions reduced the dry density value and increased the porosity.

As for Ducman and Kopar (2007), they investigated the influence of the addition of different waste products to the clay bricks. Four different waste products were selected, which were sawdust, silica and granite stone mud and papermaking sludge waste. Different percentages for each waste were carried out and the influences on the physical and mechanical properties were determined. Sawdust and paper making sludge were added up to 30% to the clay and fired around 850 °C to 920 °C. In contrast, almost 100% silica stone mud was utilised and fired at 900 °C. As for granite stone mud, the highest percentage used was 30% and fired at about 1008 °C to 1052 °C. The shrinkage after drying was reduced with the addition of sawdust but increased with papermaking sludge, silica and granite stone mud. The reduced effect was favourable as it lessened the crack formation during the drying process. The shrinkage and dry density after firing were much lower with the addition of sawdust and sludge, which acted as pore forming agents thereby increasing the porosity. The compressive strength, with 30% of sawdust, was 10.7 MPa. This was less than half of the control brick, which was 23.9 MPa. However, the addition of papermaking sludge improved the strength due to the calcite content. Hence, a combination of sawdust, papermaking sludge and clay could obtain adequate strength comparable to the control clay brick. A reduction in dry density and compressive strength was observed for the silica stone mud and granite stone mud. The compressive strength decreased from 62.5 MPa to 50.7 MPa with the addition of 50% silica stone mud and up to 10% was suggested as the optimal addition for granite stone mud to avoid a significant effect on the mechanical properties of the clay brick. In addition, both waste additives demonstrated higher water absorption.

On the other hand, Abali et al. (2007), used phosphogypsume and boron concentrator wastes to produce lightweight brick production. The firing temperatures were 100 °C, 800 °C, 900 °C and 1000 °C using additives of 1%, 3%, 5% and 20%. Boron concentrator waste could not be used in the brick as the addition of this waste resulted in the manufactured samples that crushed during firing. The phosphogypsumes used namely original phosphogypsume (OP) and washed phosphogypsume (WP) showed good potential in lightweight brick manufacturing. The advantages of incorporating the waste were reduction in mass, lower water absorption value and shorter natural drying process. Since both OP and WP produced similar good quality bricks, OP was more preferred because the additional cost incurred in producing WP. The waste also saved the fuel due to the burning of the organic substances inside the waste during the firing process. However, the physical properties have not been proven as the experimental work only emphasised the mechanical properties.

According to Sutcu and Akkurt (2009), recycled paper processing residues were also used as a raw material and organic pore-forming additive in clay bricks. The utilised proportions ranged from 10% to 30% and were fired at 1100 °C. Shrinkage was lower with the additives as were the densities, which were up to 33% less than the control brick (1.28 g/cm^3). The porosity and water absorption value increased with the inclusion of the residues with a resultant decrease in the compressive strength. However, the compressive strength value still complied with the standard strength values. The thermal conductivity was also improved by up to 50% (0.4 $W/m^{-1}K^{-1}$). The recycled paper processing residues acted as a pore-forming additive in the brick bodies, thereby improving the insulation compared to the control brick without significantly affecting the mechanical strength. Preliminary trials were successfully conducted on an industrial scale producing bricks with good thermal conductivity values.

In a recent study, the possibility of recycling cigarette butts (CBs) in fired clay bricks were investigated with very promising results (Abdul Kadir and Mohajerani 2008a, 2008b, Abdul Kadir and Mohajerani et al., 2009 and 2010, and Abdul Kadir and Mohajerani, 2010 and 2011). In this study, four different clay-CBs mixes with 0%, 2.5%, 5.0% and 10.0% by weight of CBs, corresponding to about 0%, 10%, 20% and 30% by volume were used for making fired brick samples. The results found in this study show that CBs can be regarded as a potential addition to raw materials used in the manufacturing of light-weight fired bricks for non-load-bearing as well as load-bearing applications, with improved thermal performance and better energy efficiency, providing the mix is appropriately designed and prepared for the required properties. Recycling CBs into bricks can be part of a sustainable solution to one of the serious environmental pollution problems of the world.

3. CONCLUSION

Based on the extensive literature review, the research that were carried out over the last thirty years have revealed that many successful attempts to incorporate different types of waste into the production of fired clay bricks including sludge, fly ash, polystyrene, kraft pulp residue, processed waste tea, sawdust, tobacco residues, grass, paper, cigarette butts and others. The manufactured bricks with different types of waste have shown positive effects on the properties of fired clay bricks such as improved porosity, thermal conductivity, water absorption properties, and reduction of density and energy used during firing. Thus, utilisation of solid wastes has been encouraged as one of the most cost-effective alternative materials that could be used in fired clay brick manufacturing.

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