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An Overview of Wastes Recycling in Fired Clay Bricks

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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 there are 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 by producing lightweight brick, increased porosity and improved the thermal conductivities of fired clay bricks. Nevertheless, reduced performances in number of cases in terms of mechanical properties were also demonstrated.

Keywords: 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).

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

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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. Waste Recycling

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.

3. Overview of Recycled Wastes in Fired Clay Bricks

As recycling waste is highly encouraged, the historical development of recycling waste in clay brick production has also been reviewed (Table 1). A wide range of successfully recycled materials and their effect on the physical and mechanical properties of bricks have been discussed in detail. Most of the recycled waste demonstrated both advantages and disadvantages in the brick manufacturing process. In this review, wastes used in bricks were described according to the researchers and have been divided into three main categories which are fly ash, sludge and other wastes.

Fly ash

Several researchers have tried to recycle fly ash into bricks. Kayali (2005), manufactured bricks with 100% fly ash as the solid ingredient called FlashBricks. The equipment and techniques used in manufacturing the bricks were similar to those used in the clay brick industry. Samples were fired at 1000°C to 1300°C and were formed into moulds. Fired FlashBricks produced bricks that were 28% lighter than standard clay bricks. The results show that FlashBricks improved most of the properties compared to those of a standard brick. The compressive strength obtained was 43 MPa and the tensile strength was improved almost three times compared to that of a standard clay brick. In addition, the brick also achieved a bond 44% higher than a standard clay brick and the resistance to salt exposure with zero loss of mass was excellent. In terms of appearance, the fired FlashBricks have a reddish colour similar to a standard brick but a rougher texture was observed on the surface of the brick.

In a similar study by Pimraksa et al (2001), bricks were also manufactured using 100% lignite fly ash. The effect on the mechanical properties of four different treatments of fly ash: sieved -63+40 μm fly ash, sieved -40 μm fly ash, ground 5 hour fly ash and ground 10 hour fly ash were investigated. The optimal firing temperature was between 900°C to 950°C at 3°C/min for each type of the manufactured samples. Most samples tested demonstrated less than 4% of weight loss and less than 3% of shrinkage value. The results from the experimental work conducted demonstrated that bricks manufactured with -40 μm fly ash and fired at 950°C obtained better results in mechanical strength, specifically, in compressive strength (56.3 MPa) and bending strength (13.1 MPa) compared to red fired clay bricks, common clay bricks and facing bricks. Also, some bricks manufactured with the other three types of fly ash in this study also performed better than red fired clay bricks and common clay bricks. Other properties determined in this study complied with the standards and the requirements of the market demand.

As for Lin (2006), this study used fly ash slag from the municipal solid waste incinerator (MSWI) to make fired clay bricks. The percentage of added waste varied from 10% to 40% and the bricks were fired at 800°C, 900°C and 1000°C. The results of the physical and mechanical properties indicated that using a high amount of fly ash slag increased the dry density and compressive strength value but decreased the water absorption rate. Nevertheless, all the values determined for both parameters met the Chinese National Standard (CNS) building requirements for second-class bricks. The degree of shrinkage in the firing process also decreased with the addition of fly ash slag to the mixture, which is a good indicator of the potential of the waste as a replacement for clay in bricks. All the heavy metal concentrations measured by the Toxicity Characteristics Leaching Procedure (TCLP) met the current regulatory thresholds. Furthermore, Lin (2006) recommended that using 40% of fly ash slag with 800°C as the firing temperature is optimal for producing a good quality brick while saving energy usage in the manufacturing process.

Furthermore, Lingling et al (2005) used wet low quality fly ash ranging from 50% to 80% by volume to replace clay in manufacturing fired bricks. The firing temperature used was 1050°C instead of 900°C as normally used to fire standard clay bricks. The effect of incorporating a high percentage of the pulverised fly ash was investigated and the results show that the addition increased the compressive strength value and decreased the plasticity of the brick mixture and the water absorption rate. Moreover, there was no cracking due to lime addition and a high resistance to frost melting was observed. In addition, another advantage of incorporating this waste was the high resistance of the manufactured bricks to efflorescence.

Dondi et al (1997a) also reviewed several studies regarding fly ash. 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. One of the advantages of using fly ash is that this waste saves the firing energy as its calorific value ranges from 1,470 to 11,760 kJ/kg. The other 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). However, these 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). Different particle size distribution also has an effect on the properties. Fine fly ash proved better than coarse fly ash (Anderson and Jackson, 1983) as the fine fly ash improved the dry density, firing shrinkage and mechanical properties. Moreover, the addition of fly ash also reduced efflorescence (Mortel and Distler, 1991). In addition, in certain cases, the fly ash utilisation increased the clay body plasticity and a high amount of fly ash (Anderson and Jackson, 1983) reduced the drying shrinkage, dry strength and other mechanical properties of the manufactured brick. Therefore, Dondi et al (1997b), concluded that the addition of 10% fly ash is favourable in terms of energy saving. From an economic point of view, for example, transportation costs, the results vary from very promising (Sajbulatow et al, 1980) recommendable (Mortel and Distler, 1991; Anderson and Jackson, 1983; Srbek, 1982; Usai, 1985) to unconstructive (Anonymous, 1979).

Sludge

This category includes sludge from sewage treatment plant, sludge from paper industry, iron and arsenic sludge, sludge ash and tannery sludge. 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 weight with 15% to 18% optimum moisture content is the appropriate percentage of sludge mixture to be incorporated. The compressive strength test indicated that the strength of the brick depends significantly on the amount of sludge in the brick and the firing temperature. The results showed that 15% by weight is 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 increased firing temperature. The quantity of sludge added to the mixture is inversely relative to the bulk dry density. With the right amount of moisture content in the mixture, any deformation or uneven surface were not occurred 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 are the two main factors in controlling the shrinkage in the firing process and for producing a good quality brick at the same time. Sludge proportions of 15% to 25% sludge and firing at 1000°C to 1050°C were suggested by Rouf and Hossain (2003), for producing good quality sludge bricks. They demonstrated that the original characteristics of normal clay bricks are retained with the addition of 25% sludge and that arsenic leaching is significantly reduced when bricks are burnt at a high temperature.

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 this 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 increased in percentage of sludge. With an increased firing temperature the water absorption and porosity decreased considerably. A higher firing temperature and a lower amount of sludge showed the greatest dry density of all. 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 show that the main sludge contaminant, which is chromium, might have 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. Still, the bricks application complied with the minimum requirements for the building industry and 10% tannery sludge was deemed a safe amount to be used in respect of the environmental characteristics of the product. Studies were also 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 weight 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. Yet again, 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 weight is 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 clay with dried sludge. The maximum percentage of dried municipal sludge and municipal sludge ash that could be mixed with clay for brick making is 40% and 50% by weight, 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 industrial sludge. Bricks were manufactured from industrial sludge from 30% up to 100%. The employed firing temperature was 1050°C. During the observation, cracks were prone to occur during 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% of clay. Tay et al (2002) also reported that ‘biobricks’ were manufactured by mixing clay and shale with sludge with a solid content ranging between 15% to 25%.

As for Liew et al (2004), they discussed the incorporation of sewage sludge in clay bricks and its characterisation. In this study, 10% to 40% dry weight of sludge was added to produce clay bricks. The manufactured brick was hand moulded by the compaction method and fired at 985°C. Although the surface and exterior of the sludge enhanced clay bricks were rather rough and poor a sludge content of up to 40% still complied with the required standards in terms of the physical and chemical properties. Nevertheless, the researchers concluded in this study that the maximum percentage of sludge should not be more than 30% by weight due to its fragility and that the addition of 20% sludge would maintain the functional characteristics of the brick. In general, a high amount of sludge added into the clay brick increased the drying shrinkage but decreased the firing shrinkage. The water absorption value increased by 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 included steam and CO_2, which 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 use as common bricks because of the poor exterior surface.

According to Dondi et al (1997a) in their review of previous researchers, waste from sewage sludge treatment plants was used in several studies. The waste is high in organic content, varying from 10% to 20% by mass in the incinerator of solid urban wastes to as high as 60% or even higher for sewage sludge (Mesaros, 1989). Validation on the specific amount of calorific value is hard to verify but an estimated calorific value of 10,000 kJ/kg of dry fraction is estimated to save from 10% (Mesaros, 1989) to 40% and could be higher. According to Dondi et al (1997a), a positive contribution can be achieved from less than 2% up to 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). The main advantages are related to the amount of energy saved and the environmentally friendly way for disposing of the sludge waste (Slim and Wakefield, 1991; Churchill, 1994). 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) 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 mechanical strength also decreased from 4 to 30%, and with a higher addition of sludge (40%), up to 50% reduction was observed for the strength (Tay, 1987). 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.

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 of around 8,400 kJ/kg, the weight of the brick was reduced by 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 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 in the body of the brick increased the dry shrinkage and the required water content for the manufactured brick. 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, a slight increase in water absorption, an insignificant reduction in the mechanical strength and deterioration of the fired bricks were some of the effects from 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 among the studies conducted. It was claimed that this waste offers economic benefits while still 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.

Other wastes

Krebs and Mortel (1999) also investigated various waste additives for inclusion within the bricks such as fly ash, sludge and spent grains that can be used directly in the brick. However, some types of waste had to be processed before it could be used, for example, windshield glass, PVB-foils and label papers. The main objective of these additives is to act as pore formers in the manufactured brick. A combination of pelletised old labels and fly ash obtained good results. No problem occurred during the manufacturing process. The residues utilised reduced the dry density while maintaining similar or achieving an 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 confer 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.

However, the usage of the glass grit, another waste produced from car windshields, decreased the plasticity and positively affected the firing process of the manufactured brick. Lower firing temperatures could also be employed with this additive and the brick produced offered similar strength with increased porosity that resulted in better thermal characteristics.

Krebs and Mortel (1999) also mentioned that residue from brewery waste, spent grains, have been tested on an industrial scale. The same experimental procedure that was carried out for the label pellets was conducted on the spent grains. The same positive effects were also demonstrated with this residue. The resulting light-weight bricks had improved porosity and thermal conductivities without affecting the mechanical strength.

The inclusion of fly ash (Krebs and Mortel, 1999) resulted in various advantages; it improved the thermal insulation, decreased the water content added and contributed to the firing process with its carbon content. In addition, the titanium content of the fly ash changed the colour of the brick from red to ochre.

Processed waste tea (PWT) was another waste that was noted 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, compared to the control samples indicated that the pore forming of PWT in the fired body and the binding in the unfired body have 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 supplement the heat input of the furnace and act as an organic kind of pore forming additive. The usage of the waste improved the physical and mechanical properties of the bricks and also one of the environmentally friendly alternatives in brick manufacturing.

Another waste that can be utilised in clay bricks according to Demir et al (2005) is kraft pulp production residues. Increasing amounts of the waste have been incorporated in clay bricks by 0%, 2.5%, 5% and 10%. All samples were fired at 900°C with another group being left unfired. The required water content and drying shrinkage increased with the increased amount of kraft pulp residue. Ten percent addition is not suitable due to the increased drying shrinkage. However, the addition of up to 5% residue increased the dry bending strength, which is 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.

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, improving the insulation properties. Adding organic residues increased the plasticity and, thus, increased the water content required. A residue addition of 10% is 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 by the addition of the residues. Nevertheless, the compressive strength values still complied with Turkish standards. Five percent of the residue addition was effective for pore forming but further additions reduced the dry density value and increased the porosity.

Ducman and Kopar (2007) also investigated the influence of the addition of different waste products to the clay bricks. Four different waste products were selected which were sawdust, stone mud and papermaking sludge waste. Different proportions for each waste were carried out and the influence on the physical and mechanical properties was determined. Sawdust and paper making sludge were added by 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 stone 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 is 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 that 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 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.

Dondi et al (1997a) also reviewed about recycling sawdust from the wood manufacturing industry to produce light-weight bricks. The calorific value ranged from 7,000 to 19,000 kJ/kg and saved up to 15% of the energy usage during the entire firing process. The optimum amount of sawdust added was between 4% to 5% by mass. To avoid preliminary grinding, the maximum sizes of the particles must be below 2 mm. Some researchers discovered that the use of this waste improves the workability of the clay and reduces the drying time, while some found the utilisation could cause problems during the manufacturing and drying phase. Furthermore, a reduction in the strength properties and an increase in the water content value were also observed (Isenhour, 1979). The finished product was light-weight with better thermal and acoustic properties. Water absorption was increased and the shrinkage value either remained the same or decreased slightly, however, the mechanical strength decreased considerably by up to 10% to 30%. The studies concluded that only small quantities of sawdust should be incorporated within the body of the brick (Isenhour, 1979) to gain economic and technological advantages. This is because negative effects were also demonstrated from the added waste involving gas emissions of noxious elements (Kohler, 1988; Mortel and Distler, 1991) and the formation of efflorescence (Kohler, 1988). In addition, a small number of Italian brickworks also incorporated sawdust into the body of the brick that could act as an additive as well as furnace fuel.

Other wastes incorporated in clay bricks include those derived from the textile industry; fibrous wool waste and wool wash water treatment sludge have also been examined and summarised by Dondi et al (1997a). These wastes are capable of considerable fuel savings (up to 20%) in brick manufacturing. However, the calorific values offered vary according to the origin of the wastes. Dependent on the amount of organic substance in the waste, the waste used in the body was less than 1.5% and 10% by mass of the fibrous wool and wool wash sludge, respectively. The existence of textile waste produced a light-weight brick, with increased water absorption but a lower bending strength (about 20%). However, the data concerning the efficiency of recycling this material with reference to the energy usage and economical aspects are lacking. Most of the drawbacks refer to the transport and treatment costs.

Recycling waste produced by tanning plants was also assessed by Dondi et al (1997a). Disposal sludge (Komissarov et al, 1994; Pavlova 1996) or tanned hide residues are the main waste produced by the tanning industry and it is difficult to recycle these wastes due to the existence of polluting elements, especially chromium. Considering its high calorific value (84,000 kJ/kg), with continuous monitoring of the toxicity and the environmental impact this sludge can be potentially used as a fuel. In this case, the amount of waste depends mainly on the chromium content. Therefore, only 10% of the waste was added to the clay body. The finished product waste produced a light-weight brick with good heat insulation properties. In the chrome tanned hide residues case, with 2% of mass added, the waste efficiently decreased the plasticity, the shrinkage value, bending strength and increased the porosity of the manufactured brick. Tanning wastes are potentially recyclable in bricks, however, the emission of unpleasant odours and chromium pollution has to comply with the required standards.

Dondi et al (1997a) also reported on the possibility of recycling coal-mining waste (Boldyrev, 1989; Caligaris et al, 1990; Mikhailov, 1990; Polach, 1990; Kapustin et al, 1991; Andrade et al, 1994). The waste originated from the coal mining and refining processes. The high calorific value from the coal mining and refining processes exhibited major energy savings that were estimated from 20% to 40% with the highest being 60% (Boldyrev, 1989). These wastes also consisted of inorganic components, mainly clay minerals and quartz. Some of the materials can be used as they are while others have to be refined or ground. Hence, the usual amount added is between 5% to 15% by mass (Andrade et al, 1994). However, some of the researchers recommended the use of high amounts of this waste as an alternative to the raw materials for brick making (Caligaris et al, 1990). Generally, the waste addition improved the drying behaviour and the mechanical strength of the green brick. The porosity value also increased in the fired products, while shrinkage behaviour depends on the nature of the waste added. These characteristics contributed to the mechanical strength reduction of the fired brick (Polach, 1990). In terms of technological and economic value, the utilisation of coal waste demonstrated a positive contribution as shown in some cases where low cost and good quality products were produced.

Dondi et al (1997a) also observed the incorporation of petroleum refinery waste in the brick bodies and claimed the addition guaranteed efficient fuel savings due to the high calorific value, for example, the calorific value of petroleum coke is about 31,000 kJ/kg. The percentage added of this waste is normally not more than 2.5% by mass. In the experiments conducted, the properties of bricks were maintained except for the bending strength (maximum 15%), which did not comply with the standards. Good heat insulating properties resulting from the effect of the increased porosity could be produced with 1% to 2% petroleum wax additions. Although an insignificant decrease in the mechanical strength was observed, the presence of this waste improved the drying and firing shrinkage (Almeida and Carvalho, 1991).

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 proportions utilised 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. 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.

One more waste of interest to Veiseh and Yousefi (2003) was polystyrene. The main objective of adding polystyrene foam to clay bricks is to reduce the dry density of the brick as well as 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. 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 strengths 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 ordinary bricks.

Abali et al (2007), used phosphogypsume (waste used by phosphoric acid plants) and boron concentrator wastes to produce light-weight brick production. 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 being crushed during firing. The phosphogypsume used, namely, original phosphogypsume and washed phosphogypsume, referred to as OP and WP, respectively, showed good potential in light-weight brick manufacturing. The resultant advantages of incorporating the waste included a reduction in weight, lower water absorption value and shortening of the natural drying process. Since OP and WP both produced similar good quality bricks, OP is to be preferred because of the additional cost incurred in producing WP. The waste also saves fuel due to the burning of the organic substances inside the waste during the firing process. However, the physical properties are not yet proven as the experimental work only emphasised the mechanical properties.

In another 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 show that the density of fired bricks was reduced by up to 30%, depending on the percentage of CBs incorporated into the raw materials. Similarly, the compressive strength of bricks tested decreased according to the percentage of CBs included in the mix. The thermal conductivity performance of bricks was improved by 51% and 58% for 5% and 10% CBs content respectively. Leaching tests were carried out to investigate the levels of possible leachates of heavy metals from the manufactured CB bricks. The results revealed trace amounts of heavy metals. 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.

Hegazy et al (2012), used water treatment plant and rice husk ash to be incorporated into the brick. Three different series of sludge to rice husk ash (RHA) proportions were studied with ratios of 25%, 50% and 75% by weight. Each brick proportion was fired at 900°C, 1000°C, 1100°C and 1200°C. Higher water absorption test result was obtained of sludge-RHA brick ranging between

17.41% and 73.33% compared to control brick which were 9.94% and 11.18%. The results were influenced by the firing temperature as well as the proportion of sludge and RHA in the brick. On the other hand, the specific gravity measurements were found to be in inverse correlation with the water absorption. The sludge-RHA bricks manufactured fall in the category of light weight brick (ranged from 0.78 to 1.46) compared to the control brick which ranged from 1.84 to 1.95. As for the compressive strength properties, the results for control clay brick and sludge-RHA ranged from 5.7 MPa to 6.8 MPa and from 2.8 MPa to 7.7 MPa respectively. In this experimental work, increasing the firing temperature ensures the completion of the crystallization process and closes the open pores during sintering thus reducing the water absorption but increases the specific gravity due to densification, and compressive strength property by increasing the strength of the crystalline aluminosilicate brick. On the other hand, increasing the sludge ratio will reduce the pores in the sludge RHA sinter and consequently increases the compressive strength and density. Furthermore, low portion of RHA particles is preferable compared to sludge as it significantly increases the open pores in the sinter, increasing the water absorption thus decreasing density and compressive strength. The optimum sludge-RHA recommended in this study was 75%. Most of the properties tested complied with Egyptian Standard Specifications (E.S.S).

Folanrami (2009), investigated on the effect of ashes from the burning of dried mango tree and sawdust from mahogany wood on the thermal conductivity of clay brick. Different percentages of the ash and sawdust were incorporated, which were 1%, 5%, 10%, 20% and 30% respectively and fired at 800°C. Thermal conductivity value of clay brick containing ashes ranged from 0.180 to 0.250 W/m K. On the other hand, thermal conductivity of clay brick with sawdust ranged from 0.060 to 0.230W/m K. All the manufactured clay samples with additives improved the thermal properties and the clay sample with sawdust additive (30%) gave the best value of thermal conductivity which was 0.006 W/m K.

Chan (2011) examined the physical and mechanical properties of clay brick added with two natural fibres which were pineapple leaves (PF) and oil palm fruit bunch (OF). The fibre was added within the range of 0.25% to 0.75% and fired at 800°C. Cement also was added as a binder to the mixture at 5% to 15%. Effect of PF and OF on density is not significant as it does not effect on the properties even with different percentages added into the manufactured clay brick which is different to most of other studies that used fibre or organic inclusions. Nevertheless, a slight reduction on density was observed thus also increasing the water absorption properties. As for the compressive strength, higher percentages of increase the value but higher percentages of PF decreases the strength gradually. Cement addition seems to dominate the effect on all the properties tested. All the bricks only fulfilled the minimum compressive strength of 5.2 MPa for conventional bricks according to British Standards (BS) and Malaysian Standards (MS).

Phonphuak and Thiansen (2011), studied on the physical and mechanical properties of briquettes (charcoal mixed with clay) which are density, compressive strength, water absorption and porosity. Different amount of charcoal (2.5%, 5%, 7.5% and 10% by weight) were added and fired at 900°C to 1100°C. Samples of three different sizes were manufactured which are 1 to 2 mm, 2 to 3 mm and less than 0.5 mm. The firing shrinkage (2.10% to 2.88%), water absorption (18.3% to 40.7%) and apparent porosity (31.5% to 53.9%) value increased with the increasing percentage of charcoal compared to control brick. On the other hand, bulk density (1.17 g/cm^3 to 1.68 g/cm^3), apparent density (1.87 g/cm^3 to 2.30 g/cm^3) and compressive strength (2.8 MPa to 14.1 MPa) have lower value with higher percentages of charcoal compared to the control brick. The most suitable firing temperature for test fired briquettes is 950°C because they are more durable, porous and stronger than the control bricks. Phonphuak and Thiansen (2011) conclude that charcoal could be used as a pore former additive in clay body and it also produce lightweight fired clay briquettes.

Experimental investigation was carried out by Banhidi and Gomze (2008) to improve the insulation properties of the conventional brick products. Few renewable agricultural waste materials which are sawdust, rice peel and sunflower seed shell (4% and 7% by weight) were added to the basic clay of the conventional brick mixture. The firing temperature used was 900°C with a 100°C/h heating rate. RAPID-K type of static thermal conductivity measuring instrument was used to determine thermal conductivity value of the manufactured bricks. The thermal conductivity value reduced significantly with higher percentages of the organic by product thus improved the insulation properties. The ignition of the organic by product waste addition decreased the energy used during firing by providing extra thermal energy. Pores were created during the firing process thus decreasing the thermal conductivity. The thermal value decrease by 10% to 31% compared to the control brick with 4% by weight of additives. The largest reduction was found with the addition of sunflower seed shell (37%) follow by rice peel (26%) and sawdust (16%). The thermal conductivity value decrease from 0.27 W/m K to 0.17 W/m K with 7% sunflower seed shell additive. Least improvement was obtained from the insertion of sawdust with 0.27 W/m K to 0.23 W/m K. Unfortunately, the compressive strength value decrease significantly from 26% to 77% and 25% to 48% with 4% and 7% of additives respectively. Nevertheless, in terms of mechanical properties the most suitable additive is saw dust.

Saiah et al (2010), investigate the usage of vegetable matter of various composition and shapes into fired clay bricks. The reductions of shrinkage and density value of brick were acceptable. During combustion, the vegetable matter created pores that increase the porosity from 11% to 18% thus decreased the thermal conductivity value by up to 32%. The thermal resistance improved by 18% to 48% could be expected from the manufacture brick. However, wheat straw additives show the most acceptable properties between thermal and mechanical properties.

In Ugheoke et al (2006) study, the suitability of using kaolin-rice husk-plastic clay to produce insulating firebrick was carried out and the optimal ratio of these constituents determined. Ten brick samples of different ratio were fired at a temperature of 1200ºC. During the observation, three of the samples crumbled during firing. The other seven samples gave the following limits of results: shrinkage: 9.7% to 13.6%; effective moisture content: 28.34% to 32.52%; modulus of rupture: 4.26 kgf/cm^2 to 19.10 kgf/cm^2; apparent porosity: 56% to 95.93%; water absorption: 42.27% to 92.12%; bulk density: 1.04 g/cm^3 to 1.41 g/cm^3; apparent density: 2.56 g/cm^3 to 5.77g/cm^3; and thermal conductivity: 0.005 W/m K to 0.134 W/m K. The results showed that they all had good insulating characteristics. Samples with mixing ratio of 4:1:2 (kaolin, plastic clay and rice husk respectively in grams) gave the optimum performance values in most of the properties which are shrinkage, effective moisture content, refractoriness, modulus of rupture, bulk density and thermal conductivity.

Lertwattanaruk and Choksiriwanna (2011) studied on the feasibility of incorporating 0%, 1%, 2%, 3% and 6% by weight in brick manufacturing rice husk and bagasse. The replacement of rice husk and baggase increased the compressive strength value up to 2.2 MPa and 3.2 MPa respectively compared to control brick (1.6 MPa). On the other hand, the value of shrinkage decreased from 29.99 % to 25.63 % and from 29.99 % to 17.95 %, for rice husk and bagasse respectively; when the percentages of agricultural materials increased. A decrease of shrinkage is observed with the increase of fiber proportion, but the positive effect seems to be more noticeable with bagasse. This could be attributed to a sufficient length of bagasse fiber for improving the bond at the fiber-soil interface to oppose the deformation and soil contraction (Bougerra et al., 1998; Bouhicha et al., 2005). The results obtained also indicate that the highest thermal conductivity of brick containing non-agricultural materials is 0.71 W/m K. As for the brick containing rice husk at 1%, 2%, 3% and 6% by weight, the highest thermal conductivity is 0.65 W/m K and the lowest is 0.54 W/m K. As for bagasse added at the same percentages, the thermal highest thermal conductivity is 0.65 W/m K and the lowest is 0.45 W/m K. The sample containing bagasse shows lower thermal conductivity especially at the percentage replacement of 2%, 3% and 6% by weight of materials. The incorporation of bagasse caused the positive effects in binding ability and reduction of soil contraction leading to better refinement of the pore distribution, and resulting in an increase in porosity and lowering the thermal conductivity (Biniciet al., 2007; Bouguerra et al., 1998). The moisture absorption of the brick containing rice husk and bagasse also increase accordingly with higher percentages of the material; however brick with bagasse showed the least moisture accumulation. The best percentages to incorporate both agricultural materials are 3% and 6% for rice husk and bagasse respectively.

Binici et al (2006), studied on incorporation of plastic fibre, straw and polystyrene fabric with different mixture into mud bricks. Additional material such as basaltic pumice, cement and gypsum were also added to reinforce the manufactured bricks. Mixture of plastic fibre with additional material shows the highest compressive strength (6.0 MPa) compared to the other materials. Traditional mud brick obtained the lowest compressive strength with 1.8 MPa. As for water absorption traditional mud brick have the highest value (38.7%) followed by mud brick containing straw (34.8%), polystyrene fabric (32.5%) and plastic fibre (31.1%) with additional material according to the mixture. The density values do not defer much but the highest value obtained in the plastic fibre mixture (1.263 g/cm^3) and the lowest achieved by the traditional mud brick (1.253 g/cm^3). Mixture of clay, plastic fibre, basaltic pumice and water resulted the lowest thermal conductivity (0.202 kcal/m h◦C) compared with the other mixtures. Additional basaltic pumice seems to have strong influence on the plastic fibre mixture to decrease the thermal properties. As a conclusion, different mixtures containing plastic fibre mostly comply with ASTM and Turkish Standards strength requirement.

Granite and marble sawing powder are produce enormously by industrial process in India. Generally these wastes pollute and damage the environment due to sawing and polishing processes. Dhanapandian and Gananavel (2010) carried out an experimental work by collecting granite and marble sawing powder wastes in Salem to be incorporated into the clay brick. Mixtures were prepared with 0%, 10%, 20% 30%, 40% and 50% by weight and firing temperature used is between 500◦C and 900◦C for the briquette samples. Samples of brick also were collected at Salem, Namakkal, Erode and Tamilnadu, India. During the experimental work, when the wastes were incorporated inside the current brick samples mixture from Salem, Namakkal, Erode and Tamilnadu, India, the compressive strength and flexural strength values are directly proportional with to the wastes incorporated as well as the firing temperature except for the result obtained for 10% by weight whereby the compressive strength values were reduced. The increased value of the strength may be caused by the homogeneity of the mixture due to smaller particle size of granite and marble sawing powder (Russ et al 2005). This is established by the increased in the bulk density values in this experimental work. On the other hand, water absorption and porosity values were observed to decrease proportionally with the increased of the waste content and also the firing temperature used. It shows that the waste filled the pores in the mixture appropriately thus reflect in the reduction in porosity and water absorption. All the results indicate that granite and marble sawing powder wastes could be incorporated up to 50 wt.% into raw clay materials of brick available in Salem, Namakkal and Erode districts in India and still producing adequate mechanical properties with no costly modifications in the industrial fabrication line. Furthermore, it is also found that 20 wt.% of the wastes material is the best percentages to be included compared to others.

Table 3 Overview of recycled waste in fired clay brick

RESEARCHER	WASTE MATERIAL	MIXING PERCENTAGE (%)	FIRING TEMPERATURE (°C)	PROPERTIES					
				Compressive Strength (CS) (MPa)	Density (D) (g/cm^3)	Water Absorption (WA) (%)	Shrinkage (S) (%)	Porosity (%)	Thermal Conductivity (TC) (W/mK)
Hegazy et al (2012a)	a) Water treatment sludge b) Rice husk ash (RHA)	25, 50 ,75 (by weight)	900, 1000, 1100 and 1200	5.7 to 6.8 (control brick) 2.8 to 7.7 (sludge-RHA brick)	D	9.94 to 11.18 (control brick) 17.41 to 73.33 (sludge-RHA brick)	-	I	-
Chan (2011)	a) Pineapple leaves b) Oil palm fruit bunch	0.25 – 0.75	800	2.5	I	I	-	-	-
Phonphuak et al (2011)	a) Charcoal	0, 2.5, 5, 7.5, 10 (by weight)	900 – 1100	14.9 (control brick) 2.8 to 14.1 (charcoal brick)	1.80 (control brick) 1.17 to 1.68 (charcoal brick)	17.2 (control brick) 18.3 to 40.7 (charcoal brick)	2.15 (control brick) 2.10 to 2.88 (charcoal brick)	I	-
Lertwattanaruk et al (2011)	a) Rice husk	0, 1, 2, 3, 6 (by weight)	-	1.6 (control brick) 1.8 to 2.2 (rice husk brick)	D	-	30.0 (control brick) 25.63 to 29.99 (rice husk brick)	I	0.54 to 0.65
	b) Bagasse			1.6 (control brick) 2.0 to 3.2 (baggase brick)	D	-	30.0 (control brick) 17.95 to 29.99 (baggase brick)	I	0.45 to 0.65
Abdul Kadir and Mohajerani 2008a, 2008b, Abdul Kadir and Mohajerani et al., 2009 and 2010, and Abdul Kadir and Mohajerani, 2010 and 2011).	Cigarette butt	2.5, 5.0 and 10.0 by weight	1050	26.65 (control) 3.00 to 12.57 (CB Brick)	2.12 (control) 1.48 to 1.94 (CB Brick)	5 (control) 9 to 18 (CB Brick)	I	I	1.08 (control) 0.45 to 0.85 (CB Brick)
Saiah et al (2010)	Vegetable matter	-	850 to 1150	-	2.00 (control brick) 1.50 to 1.66 (various fired clay brick)	12.5 (control brick) 22.1 to 28.6 (various fired clay brick)	I	I	367 to 247

RESEARCHER	**WASTE MATERIAL**	**MIXING PERCENTAGE (%)**	**FIRING TEMPERATURE (℃)**	**PROPERTIES**					
				Compressive Strength (CS) (MPa)	**Density (D) (g/cm^3)**	**Water Absorption (WA) (%)**	**Shrinkage (S) (%)**	**Porosity (%)**	**Thermal Conductivity (TC) (W/mK)**
Folaranmi (2009)	a) Ashes	1, 5, 10, 20, 30	800	-	D	-	-	I	0.180 to 0.240
	b) Sawdust			-	D	-	-	I	0.060 to 0.230
Dhanapandian & Gnanavel (2009)	a) Granite waste b) Marble waste	0,10,20,30,40, 50 (by weight)	500 and 900	0.33 to 0.75	I	D	-	D	-
Sutcu and Akkurt (2009)	Paper processing residues	10 to 30	1100	39.2 (control) 15.7 to 5.0 (paper residue brick)	D (33%)	16.7 (control) 23.9 to 40.4 (paper residue brick)	D	I	IM up to 50% 0.4
Banhidi & Gomze (2008)	a) Sawdust b) Rice-peel c) Seed-shell	0, 4, 7 (by weight)	900	D (25 to 77%)	D	-	-	I	0.17 to 0.27
Demir (2007)	a) Sawdust	0, 2.5, 5, 10 (by weight)	900	15.5 (control) 9.8 to 13.60 (sawdust brick)	1.80 (control) 1.35 to 1.56 (sawdust brick)	16.65 (control) 21.40 to 31.25 (sawdust brick)	4.1 (control) 4.9 to 7.4 (sawdust brick)	I	IM
	b) Tobacco Residues			15.5 (control) 8.15 to 11.55 (tobacco residue brick)	1.80 (control) 1.43 to 1.53 (tobacco residue brick)	16.65 (control) 21.85 to 29.10 (tobacco residue brick)	4.1 (control) 4.4 to 7.5 (tobacco residue brick)		
	c) Grass			15.5 (control) 8.60 to 12.35 (grass brick)	1.80 (control) 1.43 to 1.55 (grass brick)	16.65 (control) 21.65 to 29.21 (grass brick)	4.1 (control) 4.2 to 7.4 (grass brick)		

RESEARCHER	WASTE MATERIAL	MIXING PERCENTAGE (%)	FIRING TEMPERATURE (°C)	PROPERTIES					
				Compressive Strength (CS) (MPa)	Density (D) (g/cm^3)	Water Absorption (WA) (%)	Shrinkage (S) (%)	Porosity (%)	Thermal Conductivity (TC) (W/mK)
Ducman and Kopar (2007)	a) Mixture of clay, paper making and sawdust (CLAY A) b) Mixture of clay and silica stone mud (CLAY B) c) Mixture of clay and granite stone mud (CLAY C)	30	850 to 920	CLAY A 23.9 (control) 29.3 (clay A) CLAY B 62.5 (control) 52.5 (clay B) CLAY C 86.2 (control) 78.5 (clay C)	CLAY A 1.85 (control) 1.69 (clay A) CLAY B 1.96 (control) 1.90 (clay B) CLAY C 2.00 (control) 1.96 (clay C)	CLAY A 16.7 (control) 30.5 (clay A) CLAY B 9.2 (control) 16.8 (clay B) CLAY C 8.8 (control) 16.6 (clay C)	CLAY A 7.7 (control) 6.5 (clay A) CLAY B 8.4 (control) 15.4 (clay B) CLAY C 8.7 (control) 9.8 (clay C)	I	IM
Abali et al (2007)	Phosphogypsume and boron	1, 3, 5 and 20	100, 800, 900 and 1000	-	D	D	D	-	-
Ducman and Kopar (2007)	Stone mud	100 silica stone mud	900	D	D	I	I	I	IM
Binici et al (2006)	a) Plastic fibre b) Straw c) Polystyrene	0.2 2 0.6	-	1.8 (control) 4.1 to 6.0 (fibre reinforced mud brick)	1.253 (control) 1.253 to 1.263 (fibre reinforced mud brick)	38.7 (control) 31.1 to 34.8 (fibre reinforced mud brick)	-	I	0.202 to 0.241
Ugheoke et al (2006)	a) Kaolin b) Rice husk c) Plastic clay	-	1200	D	1.04 to 1.41	42.27 to 92.12%	9.7 to 13.6	-	0.005 to 0.134
Lin (2006)	Fly ash slag	10 to 40	800, 900 and 1000	I	2.5 (control) 2.7 (fly ash slag brick)	14.3 to 20.1 (control) 16.4 to 17.8 (fly ash slag brick)	D	-	-

RESEARCHER	WASTE MATERIAL	MIXING PERCENTAGE (%)	FIRING TEMPERATURE (ºC)	PROPERTIES					
				Compressive Strength (CS) (MPa)	Density (D) (g/cm^3)	Water Absorption (WA) (%)	Shrinkage (S) (%)	Porosity (%)	Thermal Conductivity (TC) (W/mK)
Demir (2006)	Processed waste tea (PWT)	0, 2.5 and 5 (by mass)	900	15.5 (control) 19.5 to 22.7 (PWT brick)	1.67 (control) 1.50 to 1.55 (PWT brick)	17.95 (control) 22.5 to 27.3 (PWT brick)	3.6 (control) 4.5 to 5.2 (PWT brick)	I	-
Demir et al (2005)	Kraft pulp	0, 2.5, 5 and 10	900	15.2 (control) 9.3 to 12.6 (kraft pulp residue brick)	1.82 (control 1.40 to 1.49 (kraft pulp residue brick)	14.46 (control) 23.47 to 37.14 (kraft pulp residue brick)	15.2 (control) 9.3 to 12.6 (kraft pulp residue brick)	I	-
Kayali (2005)	Fly ash	100	1000 to1300	40 (control) 43 (flash brick)	D (28%)	5 to 20 (control) 10 (flash brick)	-	I	-
Liew et al (2004)	Sewage sludge	10 to 40	985	13.8	-	37	I (drying shrinkage) D (firing shrinkage)	-	-
Veiseh and Yousefi (2003)	Polystyrene	0.5, 1, 1.5 and 2 (by mass)	900 to 1050	30.3 (control) 18.1 to 6.8 (polystyrene foam brick)	1.06	30.3	-	I	IM
Tay et al (2001)	Industrial sludge	30 up to 100	1050	12 to 31	-	1 to 5	D	-	-
Pimraksa et al (2001)	Lignite fly ash	100	900 to 950	56.3	D (4%)	-	D (3%)	-	-
	Windshield glass,	-	-		D	D	-	I	IM

Krebs and Mortel (1999)	PVB-foils and label papers.			I					
RESEARCHER	**WASTE MATERIAL**	**MIXING PERCENTAGE (%)**	**FIRING TEMPERATURE (ºC)**	**PROPERTIES**					
				Compressive Strength (CS) (MPa)	**Density (D) (g/cm^3)**	**Water Absorption (WA) (%)**	**Shrinkage (S) (%)**	**Porosity (%)**	**Thermal Conductivity (TC) (W/mK)**
Pavlova (1996)	a) Tanning plants	1 to 2.5	900 to 1000	-	-	25 to 29	-	-	-
	b) Ground tyres	1 to 5		-	-	23 to 29	-	-	-
	c) Fly ash	10 to 20		-	-	22 to 27	-	-	-
Komissarov et al (1994)	Tanning plants	10 to 40	950 to 1050	-	-	22	4.5	-	-
Brosnan & Hochlreitner (1992)	Sludge	33	1000	14	-	-	5	-	-
Zani et al (1991)	Paper industry	2 to 10	985	-	-	15 to 22	-	-	-
Mortel & Distler (1991)	a) Sawdust	10	920	30	-	28	4.3	-	-
	b) Fly ash	10 to 20		26 to 33	-	25 to 28	4 to 5	-	-
Mesaros (1989)	Sludge	20 to 40	950 to 1050	-	-	38 to 40	5 to 6	-	-
Alleman (1989)	Sludge	1 to 50	1015	18 to 36	-	10 to 26	-	-	-
Kohler (1988)	a) Sawdust	3 to 5	-	-	-	15 to 18	-	-	-
	b) Fly ash			-	-	10 to 11	-	-	-
Tay (1987)	Pulverised sludge ash	10 to 50	600	I	-	-	I	-	-
Usai (1985)	Fly ash	90	1000 to 1200	4 to 75	-	-	-	-	-
Anderson & Jackson (1983)	Fly ash	10 to 100	1100	1 to 28	-	5 to 25	0 to 6	-	-
Srbek (1982)	Fly ash	10 to 50	980 to 1080	20 to 25	-	24 to 37	1 to 2.5	-	-
Sajbulatow et al (1980)	Fly ash	-	1050 to 1120	10 to 21	-	14 to 25	1 to 2	-	-

I = Value increase compared to control
D = Value decrease compared to control
IM = Value improve compared to control

4. 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, rice husk, pineapple leaves, straw, baggase, sawdust, tobacco residues, grass, paper, cigarette butts and others.

The manufactured bricks incorporated with fly ash ranged from 10% up to 100%. Most of the properties demonstrated from the incorporation of fly ash into clay brick lead to the improvement of strength and density. Fly ash in the clay bodies has a plasticity reducing effect that offer lower drying and firing shrinkage and also lower water absorption that will reduce cracks formation. As for sludge waste, the composition of each waste differs according to its origin and different treatment process that applied to the waste. The quantity of waste added into fired clay brick ranged from 1% to 50%. The advantages by adding the waste sludge is the fibrous nature effect that increased the plasticity, increased the porosity after firing thus improved the thermal conductivity properties. At the same time the energy savings are estimated up to 40%. For other types of waste, most of the materials that are rich in organic substances will provide significant energy saving even with low percentages. Physical and mechanical properties improvement range from creating lightweight brick, increase the porosity and also improve the thermal conductivity.

Therefore, 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. Recycling industrial and urban waste in fired clay brick is useful if the correct percentages were incorporated and at the same time it would act as an alternative disposal method to the potential polluting wastes. Brick manufacturer will reduce the cost of raw materials, the usage of energy during firing and the improvement of the properties. Nevertheless, there are also disadvantages in using the waste such as high transportation cost, additional cost related to the need to perform on certain types of waste, gas emissions and leachate control.

References

[1]. A. Abdul Kadir & A. Abbas Mohajerani "Physico-Mechanical Properties And Leachate Analysis Of Clay Fired Bricks Incorporated With Cigarette Butts", *International Conference on Environment (ICENV), Environmental Management and Technologies Towards Sustainable Development,* 2008a, 100.

[2]. A. Abdul Kadir & A. Abbas Mohajerani, "Possible Utilization of Cigarette Butts in Light-Weight Fired Clay Bricks", *Proceedings World Academy Of Science, Engineering And Technology*, 35 (28), 2008b, 153-157, September , ISSN: 2070-3724, Paris.

[3]. A. Abdul Kadir & A. Abbas Mohajerani, "Recycling Cigarette Butts In Light-Weight Fired Clay Bricks", *Journal of Construction Materials, Proceedings of the Institution of Civil Engineers (UK)*, 2011, 164(5), 219-229.

[4]. A. Abdul Kadir & Abbas Mohajerani, A. "Possible Utilization of Cigarette Butts in Light-Weight Fired Clay Bricks", *International Journal of Environmental Science and Engineering*, 2(3), 2010.

[5]. A. Abdul Kadir, A. Abbas Mohajerani, F. Roddick & J. Buckeridge, "Density, Strength, Thermal Conductivity and Leachate Characteristics of Light-Weight Fired Clay Bricks Incorporating Cigarette Butts", *Proceedings of World Academy Of Science, Engineering And Technology*, 53(170), 2009, 1035-1041, May 2009, ISSN: 2070-3724, Japan.

[6]. A. Abdul Kadir, A. Abbas Mohajerani, F. Roddick & J. Buckeridge, "Density, Strength, Thermal Conductivity and Leachate Characteristics of Light-Weight Fired Clay Bricks Incorporating Cigarette Butts", *International Journal of Environmental Science and Engineering*, 2(4), 2010.

[7]. A. Bouguerra, A. Ledhem, F. de Barquin, R. M. Dheilly & M. Que'neudec "Effect of microstructure on the mechanical and thermal properties of lightweight concrete prepared from clay, cement and wood aggregates", *Cement and Concrete Research*, 28, 19981179-1190.

[8]. A. G. Liew, A. Idris, A. A. Samad, Calvin, H. K. Wong, M. S. Jaafar & M. B. Aminuddin, "Incorporation of sewage sludge in clay brick and its characterization", *Waste Management & Research,* (22), 2004, 226–233.

[9]. A. Knox, *An overview of incineration and EFW technology as applied to the management of municipal solid waste (MSW).* ONEIA Energy Subcommittee, University of Western Ontario, 2005.

[10]. A. Kohler, A. "Use of industrial wastes with combustible components in the brick and tile industry", *Ziegelindustries International*, 9, 1988, 441-445.

[11]. A. S. Boldyrev, "Utilization of wastes and secondary materials in building products", (Russian), *Stroit. Material,* (7), 1989, 5-7.

[12]. A. W. Hendry & F. M. Khalaf, *Masonry Wall Construction*. London and New York, Taylor & Francis Group, Spon Press, 2001.

[13]. A. Zani, A. Tenaglia & A. Panigada, "Reuse of paper making sludge in brick production", *Ziegelindustries International*, (12), 1990, 682-690.

[14]. Anonymous, "Prospective areas of Scotland's by products", *Journal Industrie Ceramique,* 88, 1979, 21-23.

[15]. B. Christine, "*Masonry Design and Detailing: For Architects and Contractors*", 5th Edition. New York, Mc-Graw Hill, 2004.

[16]. B. E. E. Hegazy, H. A. Fouad & A. M. Hassanain, "Brick Manufacturing from Water Treatment Sludge and Rice Husk Ash", *Australian Journal of Basic and Applied Sciences,* 6(3), 2012, 453-461.

[17]. B. I. Ugheoke, E. O. Onche, O. N. Namessan & G. A. Asikpo, "Property Optimization Of Kaolin-Rice Husk Insulating Fire-Bricks", *Leonardo Electronic Journal of Practices and Technologies,* 9, 2006, 167-178.

[18]. C. M. Chan, "Effect of Natural Fibres Inclusion in Clay Bricks: Physico – Mechanical Properties", *World Academy of Science, Engineering and Technology,* 2011, 51-57.

[19]. C. M. F. Vieira, P. M. Andrade, G. S. Maciel, Jr. F. Vernilli & S. N. Monteiro, "Incorporation of fine steel

sludge waste into red ceramic", *Material Science and Engineering,* 427(1-2)**,** 2006, 142–147.

[20]. D. A. Brosnan & W. Hochlretner, "Additions of oxidized sewage sludge in brick manufacture as a means of revenue generation", *Journal of the Canadian Ceramic Society,* 61 (2), 1992, 128-134.

[21]. Environmental Protection Authority, Victoria (EPAV) *Environmental guidelines for the fired clay building products industry*. Publication 607, Victoria, Australia, 1998.

[22]. F. Srbek, "Possibilities of power station ash use, fly ash as correcting admixture or fundamental raw material at brickworks", (Czech). *Stavivo*, 60, (7-8), 1982, 314-320.

[23]. G. Andrade, R. Basto & A. Vaz Serra, "Introduction of carboniferous schists in heavy clay products-exigencies of additives and products", *Journal Industrie Ceramique,* 890, 1994, 107-111.

[24]. G. C. J. Lynch, "Bricks: Properties and Classifications", *Structural Survey*, 13 (4), 1994, 15-20.

[25]. G. Usai, "Utilization of Sulcis coal ash in the production of masonry bricks", *Ziegelindustries International,* 9, 1985, 512-515.

[26]. H. Binici, O. Aksogan, B. M. Nuri, E. Akca & S. Kapur, "Thermal isolationand mechanical propertiesof fibre reinforced mud bricks as wall materials", *Construction and Building Materaials,* 21, 2007, 901-906.

[27]. H. Binici, O. Aksogan, M. N. Bodur, E. Akca & S. Kapur, "Thermal Isolation and Mechanical Properties of Fibre Reinforced Mud Bricks as Wall Materials" *Construction and Building Materials*, 2006, 1-6.

[28]. H. Mortel & P. Distler, "Use of fly ash in the production and process optimization of backing bricks", *Ziegelindustries International* (8-9), 1991, 424-428, 464-470.

[29]. I. Demir, "An investigation on the production of construction brick with processed waste tea", *Building and Environment,* 41, 2006, 1274-1278.

[30]. I. Demir, "Effect of organic residues addition on the technological properties of clay bricks", *Waste management***,** 28, 2008, 622-627.

[31]. I. Demir, M. S. Baspinar & M. Orhan "Utilization of kraft pulp production residues in clay brick production", *Building and Environment,* 40 (11), 2005, 1533–1537.

[32]. J. A. Slim & R. W. Wakefield, "The utilization of sewage sludge in the manufacture of clay bricks", Water SA, 17 (3), 1991.

[33]. J. E. Allemen, "Beneficial use of sludge in building components, 1, Concept review and technical background", *Interbrick*, 3 (2), 1987, 14-18.

[34]. J. E. Allemen, "Beneficial use of sludge in building components, 2, Full scale production of sludge amended bricks", *Interbrick,* 5(1), 1989, 28-32.

[35]. J. Folaranmi, "Effect of Additives on the Thermal Conductivity of Clay", *Leonardo Journal of Sciences*, 14, 2009, 74-77.

[36]. J. H. Tay, "Bricks manufactured from sludge", *Journal Environmental Engineering,* 113 (2), 1987, 278.

[37]. J. H. Tay, "Bricks manufactured from sludge", *Journal of Environmental Engineering Div., Am. Soc. Civ. Eng.*, 113, 1987, 278-283.

[38]. J. H. Tay, "Sludge and incinerator residue as building and construction materials", *Proceedings lnterclean '84 Conf., Singapore,* 1984, 1984, 252-261.

[39]. J. H. Tay, "Sludge as brick making material", *Proceedings on New Directions and Research in Waste Treatment and Residual Management*, Vancouver, *Canada*. 2, 1985, 661.

[40]. J. H. Tay, K. Y. Show & S. Y. Hong, "The application of industrial sludge and marine clay in brick making", *Proceedings of IWA Conference on Sludge Management Entering the 3rd Millennium. IWA, 25-28 March, Taipei, Taiwan.* R.O.C., 2001, 702-704.

[41]. J. H. Tay, K. Y. Show, J. Y. Wang & S. Y. Hong, "Constructive approach for sludge management-new resource from sludge", *Proceedings Second International Workshop on Recycling, Japan National Institute of Advanced Industrial Science and Technology, 2-5 December, Tsukuba, Japan,* 2002.

[42]. J. J. R. C. V. Almeida & J. A. L. Carvalho, "Incorporation of petroleum waxes in clay bricks" *Industrie Ceramique,* 11 (4), 1991, 194-197.

[43]. J. P. Mamlouk & M. S. Zaniewski, "*Materials for Civil and Construction Engineers",* 2nd Edition. Upper Saddle River, New Jersey, Pearson Prentice Hall, 2006.

[44]. K. L. Lin, "Feasibility study of using brick made from municipal solid waste incinerator fly ash slag", *Journal of Hazardous Materials,* 137, 2006, 1810-1816.

[45]. K. Pimraksa, M. Wilhelm, M. Kochberger & W. Wruss, "A new approach to the production of bricks made of 100% fly ash", *International Ash Utilization Symposium, Center for Applied Energy, University of Kentucky*, 2001.

[46]. K. Y. Show & J. H. Tay, "Constructive approach for sludge management–new resource from sludge", *Resources, Conservation and Recycling*, 1992.

[47]. Kapustin, A. P., Kalmykova, L. F. & Stanevich, V. T. (1991) Ceramic production making use of coal mining wastes of Ekibastuzsky basin (Russian). *Stroit. Material,* (10), 13-14.

[48]. L. Kutassy, "Utilization of special wastes in the brick and tile industry (Hungarian)", *Epitoanyag,* 34 (9), 1982, 332-335.

[49]. L. Pavlola, Use of industrial waste in brick manufacture. *Tile & Brick International*, 12 (3), 1996, 224-225.

[50]. M. A. Rouf & M. D. Hossain, "Effects of using arsenic-iron sludge in brick making", *Fate of Arsenic in the Environment, Proceedings of the BUET-UNU International Symposium, 5–6 February, Dhaka, Bangladesh,* 2003, 193-208.

[51]. M. Anderson & G. Jackson, "The beneficiation of power station coal ash and its use in heavy clay ceramics", *Transactions and Journal of the British Ceramic Society,* 82, 1983, 50-55. *Proceedings 5th CERP Conference.*

[52]. M. Bouhicha, F. Aouissi, & S. Kenai, "Performance of composite soil reinforced with barley straw", *Cement and Concrete Composites*, 27, 2005, 617-621.

[53]. M. Churchill, "Aspects of sewage sludge utilization and its impact on brickmaking", *Global Ceramic Review,* 1, 1994, 18-21.

[54]. M. Dondi, M. Marsigli & B. Fabbri, "Recycling of industrial and urban wastes in brick production-A review (Part 2)", *Tile & Brick International,* 13 (4), 1997b, 302-315.

[55]. M. Dondi, M. Marsigli & B. Fabbri, “Recycling of industrial and urban wastes in brick production-A review”, *Tile & Brick International,* 13 (3), 1997a, 218-225.
[56]. M. Sutcu & S. Akkurt, “The use of recycled paper processing residues in making porous brick with reduced thermal conductivity”, *Ceramics International,* (35), 2009, 2625-2631.
[57]. N. Phonphuak & S. Thiansen, “Effects of Charcoal on Physical and Mechanical Properties of Fired Test Briquettes”*, Science Asia,* 37, 2011, 120-124.
[58]. O. Kayali, “High performance bricks from fly ash”, *Proceedings of the World of Coal Ash Conference, Lexington, Kentucky,* 2005.
[59]. P. Lertwattanaruk & J. Choksiriwanna, “The Physical and Thermal Properties of Adobe Brick Containing Baggase for Earth Construction”*Journal of Architectural/Planning Research and Studies*, 5(1), (2011), 187-199.
[60]. P. Polach, “Effect of combustible additions on the properties of brick bodies”, *Proceedings 8th Silichem Conference*. 1990, 157-158.
[61]. R. E. Caligaris, L. A. Zamboni, C. D. Ortiz, & M. G. Calligaris, “Bricks from coal tailings”, *Tile & Brick International,* 6 (4), 1990, 41-42.
[62]. R. Mesaros, “Use of sludge from the municipal sewage system for brickmaking, new life for obsolescent brickwork”, *Ziegelindustries International* 5, 1989, 251-254.
[63]. R. Saiah, B. Perrin & L. Rigal, “Improvement of Thermal Properties of Fired Clays by Introduction of Vegetable Matter”, *Journal of Building Physics*, 34(2), 2010, 124-142.
[64]. S. A. Komissarov, T. M. Korchuganova & A. V. Belyako, “Construction materials using tanning industry wastes”, *Glass & Ceramics,* 51 (1-2), 1994, 32-34.
[65]. S. Dhanapandian, & B. Gnanavel, “Using Granite and Marble Sawing Power Wastes in the Production of Bricks : Spectroscopic and Mechanical Analysis”, *Research Journal of Applied Sciences, Engineering and Technology,* 2(1), 2009, 73-86.
[66]. S. Krebs & H. Mortel, “The use of secondary pore forming agents in brick production”, *Tile & Brick International*, 15 (1), 1999, 12- 18.
[67]. S. Sh. Sajbulatow, K. K. Kuathaew & E. M. Rontschinskij, “The production of bricks from power generating station ash”, *Ziegelindustries International,* 9, 1980, 579-581.
[68]. S. Veiseh & A. A. Yousefi, “The use of polystyrene in lightweight brick production”, *Iranian Polymer Journal,* 12, (4), 2003, 324-329.
[69]. T. Basegio, F. Berutti, A. Bernades & C. P. Bergmann, “Environmental and technical aspects of the utilization of tannery sludge as a raw material for clay products”, *Journal of the European Ceramic Society*, 22(13), 2002, 2251-2259.
[70]. T. W. Marotta & C. A. Herubin, “Basic *Construction Materials”*, 5th Edition. New Jersey, Prentice-Hall, 1997.
[71]. V. Ducman & T. Kopar, “The influence of different waste additions to clay product mixtures”, *Materials and Technology*, 41 (6), 2007, 289-293.
[72]. V. I. Mikhailov, “Ceramic brick production from coal wastes of Ekibastuzsky basin”, (Russian). *Stroit. Material*, 9, 1990, 5-6.
[73]. V., Bandihi, & L. A. Gomze, “Improvement of Insulation Properties of Conventional Brick Products”, *Materials Sciences*, 589, 2008.
[74]. W. Russ, H. Heinrich Mortel & R. Meyer-“Application of spent grains to increase porosity in bricks”, *Construction Building Material*, 19, 2005, 117-126.
[75]. X. Lingling, G. Wei, W. Tao & Y. Nanru, “Study on fired bricks with replacing clay by flash in high volume ratio”, *Construction and Building Materials,* 19, 2005, 243-247.
[76]. Y. Abali, M. A. Yurdusev, M. S. Zeybek & A. A. Kumanhoglu. “Using phosphogypsume and boron concentrator wastes in light brick production”, *Construction and Building Materials,* 21, 2007, 52-56.