A review on bricks and stabilized compressed earth blocks

Sadek Deboucha* and Roslan Hashim

Department of Civil Engineering, Faculty of Engineering, University of Malaya, Lembah Pantai, 50603 Kuala Lumpur, Malaysia.

Accepted 18 March, 2010

This paper is a review of the state of uses of clay bricks and stabilized compressed earth blocks. We offer an overview of the world general building using clay bricks or stabilized compressed earth blocks compiled from various research organizations, modern projects which have been carried out and reports from existing manufacturing of clay bricks or stabilized compressed earth blocks. Although, stabilized compressed earth blocks as construction materials are highly unknown to most people, its advantages are seen in terms of rescuing the heritage and also as rediscovered environmentally-friendly building materials.

Key words: Clay bricks, stabilized compressed earth blocks.

INTRODUCTION

The history of civilization is synonymous to the history of masonry. Man’s first civilization, which started about 6000 years ago, was evident from the remains of the Mesopotamians masonry heritage. During those days, masonry buildings were constructed from any available material at hand. The Mesopotamians used bricks, made from alluvial deposits of the nearby River Euphrates and Tigris to build their cities beside two rivers. Where civilization existed in the vicinity of mountains or rocky outcrops, stone was used. The Egyptian pyramids that existed along the rocky borders of the Nile valley were examples of such stone masonry. In the Eastern civilization, remains of historical masonry are the reputed Great Wall of China, which is considered as one of the seven construction wonders in the world.

The prevision of good quality housing is recognized as an important responsibility for welfare of people in any country. For this, building materials based on natural resources are often used. Some examples are the use of clay for making bricks, and river sand for making cement sand blocks. The commercial exploitation of these resources often leads to various environmental problems. If clay mines are not properly filled up, they can collect water and allow mosquitoes to breed. Extensive sand mining can lower the river-beds and allow salt-water intrusion inland. Therefore, the development of many alternative walling materials as possible will be of immense benefit to minimize the impact on the environment. Earth can be used for construction of walls in many ways. However, there are few undesirable properties such as loss of strength when saturated with water, erosion due to wind or driving rain and poor dimensional stability. These drawbacks can be eliminated significantly by stabilizing the soil with a chemical agent such as cement. Cement stabilized soil is generally used as individual blocks compacted either with manual hydraulically operated machines. Significant research data are available for these applications either as block strength or wall strength (Perera and Jayasingh, 2003; Reddy and Jagadish, 1989).

The early forms of masonry application in Malaysia dated back about 350 years ago with the construction of the Stadthuys in Malacca, built by the Dutch in 1650. The British colonized the Malaysia Peninsula initiated a more modern form of masonry construction. Brickwork buildings were at that time built specially for government offices, quarters and residential homes. The administrative block, Sultan Abdul Samad building built in 1894 and given a face-lift during the Fourth Malaysia Plan (1981-1985) is an example of a masonry heritage, which stands as a remarkable landmark of Kuala Lumpur. During the

*Corresponding author. E-mail: eng.sadek30@gmail.com. Tel: 6016 981 8692. Fax: 603 7967 5318.
last few years, there has been a growing interest in the use of earth as a modern construction material and also considered as a sustainable material. Some of the reasons for this are the energy saving in manufacturing compared to clay bricks, the cement used was compared to concrete blocks, the transport savings, if soil comes from the construction site or vicinity and the natural appearance and colours that help buildings integrate into the landscape (Carmen and Ignacio, 2005). In Malaysia, there is more research needed in the area of stabilized earth for constructing materials and the problems faced in using it today.

Production of earth materials

**Clay bricks**

Brick is a ceramic material mainly used in construction industry. Its production process involves forming of clay into rectangular blocks of standard size, followed by firing to temperature ranging from 900 - 1200 °C. It is made of clay or shale and when given desired shape is dried and fired into a durable ceramic product. Brick is one of the most important building materials. Energy consumption and pollution are the two important environmental and cost concerns related to the brick industry. A report, in 1993, indicated that more than 3000 brick kilns in operation in the country with an annual growth of 3% (Egbert, 1993). Old rubber, low quality coal, wood and used-oil were reported as fuel in most brick kilns. Consumption of these fuels, combined with inefficient combustion process produces large quantity of hazardous gases that threaten the environment as walls as those working in brick kilns. Since long, in fact, the brick-industry in the country has remained mostly traditional with no importance to enhancement or standardization of physical properties of the final product at all. Among the problems faced by the industry, the first and probably the most important is the supply of reasonably priced fuel in the form of fuel wood as walls as coal. A second major problem is that the industry is not walls organized and technically ill prepared with very little know-how about it and few engineers and scientists having taken interest in this industry (Egbert, 1993).

The history of brick industry is very old and can be traced back to about 5000 years old. Understanding of the brick, microstructure as influenced by the range of temperature during firing cycle has been enhanced by the experimental work in this area. For example, Convile et al. (2005) investigated the micro-structural evolution of various clays using XRD and TEM. They observed that, the pseudo-hexagonal morphology of the kaolinite changed to pseudo-hexagonal meta-kaolin at around 550 °C with meta-kaolin broken down at temperatures > 900 °C to γ-alumina-type spinal and a silica-rich phase. The spinal type phase started to transform into mullite at > 1000 °C. At 1300 °C, mullite increased in size to ~1 μm and in some regions, cristobalite formed from the silica rich matrix (Convile et al., 2005; Lee et al., 1999). XRD, TGA/DTA and EF-TEM studies of clay have revealed that meta-kaolin partially transforms to γ-alumina at 920 °C (Peters and Iberg, 1978) Figure 1. On further increase in the firing temperature to > 940 °C, the crystallization of Al2O3-rich mullite began and excess amorphous silica was discarded into the matrix (Peters and Iberg, 1978). Mullite begins to crystallise at 1050 °C and its crystal size increases with increase in firing temperature (Convile et al., 2005). A number of phases are usually present in fired bricks. Quartz is observed in all samples, usually less abundant in the brick than in the raw material. Hematite is also present in all samples, which impart the red colour to bricks. Even in yellow bricks, the presence of Hematite is observed though in smaller amounts (Amjad, 2000).

**Clay brick strength**

Compressive strength of brick is important as an indicator of masonry strength and as a result brick strength has become an important requirement in brickwork design. A considerable amount of past research and studies on masonry indicated that stronger bricks contribute to greater brickwork strength (Hendry, 1990; Lenczer, 1972; Sahlin, 1971).

In Singapore, Standard SS 103 (1974), compressive strengths are classified as First, Second and Third Grade with minimum compressive strength of 35, 20 and 5.2 N/mm², respectively. Figure 2 shows the relationship between strength of brick and strength of wall. The British standard (BS, 3921, 1985) categorized compressive strength into classes of engineering A and B presented in Table 1. These classifications of bricks commonly used.
for construction with aesthetics and strength requirements. All other brick and damp-proof course bricks should have strengths not less than 5 N/mm². However, the damp-proof course is divided into two in accordance to water absorption.

In the American Standard (ASTM), compressive strengths are classified in accordance to the different grades of weathering and exposure condition as indicated in Table 2. The grades of weathering can be negligible (NW), moderate (MW) or severe (SW) depending on the damp zoning as given in ASTM. According to the Australian Standard (AS 1225 - 1984) the characteristics compressive strength characteristics is specified, against values for the ratio of manufacturing height to manufacturing width as reflected in Table 3.

**Clay brick water absorption and durability**

The effects of brick absorption property due to variable raw materials used in its manufacturing Surej et al. (1998). Water absorption of bricks is usually measured by 5 h boiling and 24 h cold immersion test. The 24 h cold immersion test allows water to be absorbed into pores, which are easily filled under cold condition while the 5 h boiling test gives fully saturated condition where all pores are filled up with water. The saturation coefficient ranges from about 0.4 - 0.95; the lower value of around 0.4 indicates high durability and higher values of around 0.95, low durability (Khalaf and Venny, 2002). Other durability indices have also been developed based on relationship of porosity and water absorption. Table 4 shows the durability indices developed by Surej et al. (1998).

These durability indices, which are function of porosity and water absorption of bricks is shown in the Equation 1. DIAP (C) and DIAP (S) refer to durability index which is based on absorption properties derived from the cold immersion absorption property and suction property, respectively.

\[
DIAP(C) = -\frac{450.70}{(2.94 + B)} + 387.98 \left(0.87 - \frac{C_1}{B}\right)
\]

\[
DIAP(S) = -\frac{450.70}{(2.94 + B)} + 329.81 \left(0.97 - \frac{S_4}{B}\right)
\]

Where,
B is the absorption due to 5 h boiling.
C1 is the absorption due to 1 h immersion absorption.
S4 is the capillary suction achieved similar test as in the

**Table 1. Classification of bricks by compressive strength and water absorption (BS 3921:( 1985)**

<table>
<thead>
<tr>
<th>Class</th>
<th>Average compressive Strength (N/mm²)</th>
<th>Water absorption (5 h Boiling) % by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering A</td>
<td>≥70</td>
<td>≤4.5</td>
</tr>
<tr>
<td>Engineering B</td>
<td>≥50</td>
<td>≤7.0</td>
</tr>
<tr>
<td>Damp-proof course 1</td>
<td>≥5</td>
<td>≤4.5</td>
</tr>
<tr>
<td>Damp-proof course 2</td>
<td>≥5</td>
<td>≤7.0</td>
</tr>
<tr>
<td>All others</td>
<td>≥5</td>
<td>No limits</td>
</tr>
</tbody>
</table>

**Figure 2.** Mean compressive strength of walls against strength for 102 mm thick brickwork in various mortars Hendry, (1990).
Table 2. Physical requirement for building bricks (ASTM C62-89a, 1990).

<table>
<thead>
<tr>
<th>Designation</th>
<th>Minimum compressive strength, brick flat wise (N/mm²)</th>
<th>Maximum water absorption (5 h boiling), %</th>
<th>Maximum saturation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average of 5 bricks</td>
<td>Individual</td>
<td>Average of 5 bricks</td>
</tr>
<tr>
<td>Grade SW</td>
<td>3000(20.7)</td>
<td>2500(17.2)</td>
<td>17.0</td>
</tr>
<tr>
<td>Grade MW</td>
<td>2500(17.2)</td>
<td>2200(15.2)</td>
<td>22.0</td>
</tr>
<tr>
<td>Grade NW</td>
<td>1500(10.3)</td>
<td>1250(8.6)</td>
<td>No limit</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Ration of manufacturing height to manufacturing width</th>
<th>Characteristics compressive strength, Mpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0.7</td>
<td>7.0</td>
</tr>
<tr>
<td>≥ 2</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Table 4. Limit of durability indices (Surej et al, 1998).

<table>
<thead>
<tr>
<th>Index</th>
<th>Limiting values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Durable</td>
</tr>
<tr>
<td>DIAP(C)</td>
<td>&gt; 90</td>
</tr>
<tr>
<td>DIAP(S)</td>
<td>&gt; 85</td>
</tr>
</tbody>
</table>

Clay brick density

Raw materials and manufacturing process affect bricks density, which could vary between 1300 - 2200 kg/m³. The density of bricks influences the weight of walls and the variations in weight have implications on structural, acoustical and thermal design of the wall. Incorrect assumptions on wall weight can result in inaccurate dead loads and seismic loads, reduced factor of safety in shear walls and overestimate of acoustical transmission loss (Grimm, 1996).

Stabilized compressed earth blocks

The new technology focuses on stabilized earth masonry brick development incorporating an industrial by-product material, which is vital for the future of construction. The stabilized earth masonry brick technology relies on the use of an activated industrial by-product (Ground Granulated Blast-furnace Slag – GGBS) and natural earth. Due to the use of a by-product material in the formulation, it is anticipated that the final pricing of the stabilized earth masonry building brick will be reduced. The added environmental advantage of utilizing industrial by-products available in the country will further improve the sustainability profile of masonry brick production. The use of a cement replacement material (GGBS) with a lower environmental burden offers opportunities for significant reductions in energy use and carbon dioxide emissions. One of the most effective alternatives to Portland cement is GGBS, which has the potential to typically replace up to 80% of the Portland cement (Oti et al., 2008a). GGBS has extremely low energy usage and CO₂ emission when compared with PC. The energy usage of 1 ton of GGBS is 1300 MJ, with a corresponding CO₂ emission of just 0.07 ton Higgins (2007), while the equivalent energy usage of 1 ton of PC is about 5000 MJ Higgins (2007), with at least 1 ton of CO₂ emitted to the atmospheres (Wild, 2003).

Literature review on stabilized earth masonry bricks/blocks revealed that there is a growing interest in stabilized earth building materials development with respect to an energy conscious and ecological design, which fulfils all strength and serviceability requirements for thermal transmittance. There are previous researches studies reported on compressive strength and erosion characteristics of earth blocks/rammed earth wall (Heathcote, 1991; Walker 2004; Jayasinghe and Kamaladasa, 2007). The work by (Jayasinghe and Mallawaarachchi, 2009) was on flexural strength of compressed stabilized earth masonry materials. Reddy et al. (2007) reported on enhancing bond strength and characteristics of soil-cement block masonry. This resurgence of renewed research interest in recent years in stabilized earth building bricks may be partially due to its potential as a commercial construction material. The fact that, a single element can fulfill several functions including structural integrity, thermal transmittance and durability in service makes the material an excellent walling material when compared to the fired earth bricks used in mainstream construction of today.

Earth as a construction material has been used for thousands years by civilizations all over the world. Many different techniques have been developed; the methods used vary according to the local climate and environment as walls as local traditions and customs. As a modest estimate, it is thought that as many as 30% of the world’s
populations live in a home constructed in earth (Houben and Guillaud, 1994). The compressed earth block is a modern descendent of moulded earth block, more commonly known as the adobe block. The idea of compacting earth to improve the quality and performance of moulded earth blocks is, however, far from new and it was with wooden tamps that the first compressed earth blocks were produced. The first machines for compressing earth probably dated from the 18th century. But the turning point in the use of presses and the way in which compressed earth blocks were used for building and architectural purpose came only in effect from 1952, following the invention of the famous little CINVA-RAM press, designed by engineer Raul Ramirez as walls as its technical worth. During the 1950s, use of the material was widely disseminated. In 1960s and early 1970s were however stagnant years. This was to change the 1976 Vancouver Assembly of the United Nations conference on Human Settlement.

Continued interest in CSBs (Cement Stabilized Blocks) will in the future evolve around the several merits and attractions associated with its use. Firstly, as the basic raw material is soil, its source will remain abundant. This facilitates direct site-to-service application, thereby, lowering costs normally associated with acquisition, transportation and production. Home ownership can then be delivered at comparatively low costs. Secondly, the initial performance characteristics of the material such as the wet compressive strength (WCS) dimensional stability, total water absorption (TWA), block dry density (BDD) and durability are technically acceptable. They are also comparable to those of rival materials (ILO: International Labour Organization, 1987; Houben and Guillaud, 1994; Houben et al., 1996). Houses constructed of CSBs also uniquely offer better internal climatic conditions than other modern materials (Fullerton, 1979; Hughes, 1983). Thirdly, promoting the use of CSBs generates more direct and indirect employment opportunities within the local populace than would be in the case with other materials. Fourthly, use of the material contributes directly to the social, cultural and educational advancement of the population (Schumacher, 1973; Anderson et al., 1982; Aksa, 1984). Cement blocks were found to be a major construction material in both urban and peri-urban areas and are increasingly becoming the basic walling material in these areas.

The block quality obtained for a given production cost is much below that which could be achieved. Problems were observed with raw material testing, cement optimization, mixing, batching, mould filling, compaction and curing. These problems could be reduced if producers were more informed, better skilled, equipped with better production and testing equipment and more diligent in quality control. It was found that micro-enterprise production of soil-cement could offer cost savings over sandcrete walling (www.earth ouroville.com). The cost advantage is small (0 - 30%) for built-up walling using current soil-cement block production systems. Soil-cement blocks are usually smaller than sandcrete blocks and consequently, they are more costly to lay because of the increased laying time and additional mortar required per square meter. Using local cost data for predictions, it was found that further savings, in the order of 50%, are potentially possible if impact compaction of larger size soil-cement blocks (equivalent to the size of current sandcrete blocks) were investigated. However, it was found that at present, soil-cement is disadvantaged by the incorrect perception that, it is not a "permanent" building material; it is strongly associated with traditional unstabilized soil construction in the minds of many. It was found that nomenclature was the prime reason for this association and that this may be remedied through the removal of "soil" from the material's name. The soil, raw or stabilized, for compressed earth block (CEB) is slightly moistened, poured into press (with or without stabilizer) and then compressed either with a manual or motorized press. CEB can be compressed in many different shapes and sizes. The input soil stabilization allowed building with thinner walls, also, having better compressive strength and water resistance. With cement stabilization, the blocks must be cured for four weeks after manufacturing.

Subsequently, it can be used like common bricks with a soil cement stabilized mortar. Since the early days, compressed earth blocks are most of the time stabilized. Many stabilizers can be used. Cement and lime is the most common ones. Others, like chemicals, resins or natural products can be used as wells.

Compressive strength

The compressive strength of compressed stabilized earth building blocks (that is, the amount of pressure can resist without collapsing) depends upon the soil type, type and amount of stabilizer and the compaction pressure used to form the block. Maximum strengths (described in MN/m²) are obtained by proper mixing of suitable materials and proper compacting and curing.

In practice, typical wet compressive strengths for compressed stabilized earth building blocks may be less than 4 MN/m². However, some Sudanese black cotton soil when stabilized with hydrated high calcium lime to give wet compressive strengths in the range of 6 - 8 MN/m², strength suitable for many building purposes. It also competes favourably, for example, with the minimum British Standard requirements of 2.8 MN/m² for precast concrete masonry units and load bearing fired clay blocks and of 5.2 N/m² for bricks.

Where building loads are small (e.g. in the case of single storey constructions), a compressive strength of 1 - 4 MN/m² may be sufficient. Many building authorities around the world recommend values within this range (CDE, 1998).
Table 5. Properties of compressed stabilized earth blocks versus other walling materials (Adam, 2001).

<table>
<thead>
<tr>
<th>Property</th>
<th>Compressed stabilized earth blocks</th>
<th>Fired clay bricks</th>
<th>Calcium silicate bricks</th>
<th>Dense concrete blocks</th>
<th>Aerated concrete blocks</th>
<th>Lightweight concrete blocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet compressive strength (MN/m$^2$)</td>
<td>1 - 40</td>
<td>5 - 60</td>
<td>10 - 55</td>
<td>7 - 50</td>
<td>2 - 6</td>
<td>2 - 20</td>
</tr>
<tr>
<td>Moisture Movement (%)</td>
<td>0.02 - 0.2</td>
<td>0.00 - 0.02</td>
<td>0.0 - 0.035</td>
<td>0.02 - 0.05</td>
<td>0.05 - 0.10</td>
<td>0.04 - 0.08</td>
</tr>
<tr>
<td>Density(kg/m$^3$)</td>
<td>1700 - 2200</td>
<td>1400-2400</td>
<td>1600-2100</td>
<td>1700-2200</td>
<td>400 - 950</td>
<td>600 - 1600</td>
</tr>
<tr>
<td>Thermal Conductivity W/mºC</td>
<td>0.81 - 1.04</td>
<td>0.70 - 1.30</td>
<td>1.10 - 1.60</td>
<td>1.00 - 1.70</td>
<td>0.10 - 0.20</td>
<td>0.15 - 0.70</td>
</tr>
<tr>
<td>Durability Against rain</td>
<td>Good to</td>
<td>Excellent to</td>
<td>Good to</td>
<td>Good to</td>
<td>Good to</td>
<td>Good to</td>
</tr>
</tbody>
</table>

Density and thermal properties

Normally, compressed stabilized earth blocks are denser than a number of concrete masonry products such as aerated and lightweight concrete blocks. Table 5 shows the range of various types of bricks e.g. clay, calcium silicate and concrete bricks.

The high density of compressed stabilized earth blocks may be considered as an disadvantage when the blocks have to be transported over long distances; however, it is of little consequence when they are produced at or near the construction site. Low density compressed stabilized earth blocks have an advantage over high density ones of acting as better thermal insulators.

This is particularly, advantageous in hot dry climates where extreme temperatures can be moderated inside buildings made of compressed stabilized earth blocks. For example, the El Haj Yousif School in Sudan as presented in Figure 3 (Adam, 2001).

Advantage of compressed earth blocks (CEB)

(i) Soil is available in large quantities in most regions.
(ii) Cheap and affordable - in most parts of the world soil is easily accessible to low-income groups. In some locations it is the only material available.
(iii) Easy to use - usually no specialized equipment is required.
(iv) Suitable as a construction material for most parts of the building.
(v) Fire resistant - non-combustible with excellent fire resistance properties.
(vi) Beneficial climatic performance in most regions due to its high thermal capacity, low thermal conductivity and porosity, thus, it can moderate extreme outdoor temperatures and maintain a satisfactory internal temperature balance.
(vii) Low energy input in processing and handling soil - only about 1% of the energy required manufacturing and
processing the same volume of cement concrete. This aspect was investigated by the Desert Architecture Unit which has discovered that the energy needed to manufacture and process one cubic meter of soil is about 36 MJ (10 kWh), while, that required for the manufacture of the same volume of concrete is about 3000 MJ (833 kWh). Similar findings were also reported by habitat.

(viii) Environment appropriateness - the use of this, almost unlimited its natural state involves no pollution and negligible energy consumption, thus, there is further benefit of the environment by saving biomass fuel.

CONCLUSION

Based on the review of both experimental and filed investigation on clay bricks and stabilized compressed earth blocks, the following concluding remarks can be drawn:

(i) Major usage in the world for construction is clay bricks; many researchers are presently looking for newer options because they need low cost materials, which are also environmentally friendly. The process of manufacturing clay bricks also requires high energy to burn due to the emission of CO₂ gas from this process.

(ii) Stabilized compressed earth blocks include; uniformed building component sizes, use of locally available materials and reduction of transportation. Uniformly, sized building components can result in less waste, faster construction and the possibility of using other pre-made components or modular manufactured building elements. Such modular elements as sheet metal roofing which can be easily integrated into a CEB structure.

(iii) The use of natural, locally-available materials makes good housing available to more people, and keeps money in the local economy rather than spending it on imported materials, fuel and replacement parts.

(iv) The earth used is generally subsoil, leaving topsoil for agriculture. Building with local materials can provide employment for local people, and definitely considered more sustainable in times of civil economic difficulties.

(v) People can often continue to build good shelters for themselves regardless of the political situation of the country.

(v) The reduction of transportation time, cost and attendant pollution can also make CEB more environmentally friendly than other materials.

ACKNOWLEDGEMENT

Major financial support for the research was provided by the Postgraduate Research Fund PS115-2008C under the University of Malaysia Research University Grant.

REFERENCES


