

Properties of Laterite Brick Reinforced with Oil Palm Empty Fruit Bunch Fibres

Sallehan Ismail^{1*} and Zaiton Yaacob²

¹*Department of Building,
Faculty of Architecture, Planning & Surveying,
Universiti Teknologi MARA, Seri Iskandar Campus,
32610 Seri Iskandar, Perak, Malaysia*

²*Department of Building,
Faculty of Architecture, Planning & Surveying,
Universiti Teknologi MARA Malaysia,
40450 Shah Alam, Selangor, Malaysia*

**E-mail: salle865@perak.uitm.edu.my*

ABSTRACT

The development of a new, low-cost building material that is composed of non-fired, pressed laterite bricks incorporating oil palm empty fruit bunches (OPEFB) fibre was investigated in this study. The main aim of this research was to study the physical and mechanical properties of laterite brick reinforced with OPEFB fibre, including dimensions, weight, density, water absorption and compressive strength. The tests were carried out according to BS 3921:1985 for water absorption and compressive strength tests. The mix proportion of the control bricks was 70% soil, 24% sand, and 6% cement. Meanwhile, the OPEFB fibre contents ranged from 1% to 5% by weight of cement. The specimens were taken from a total of 120 bricks. The findings withdrawn from this research were: firstly, the density of laterite bricks was decreased with the increase in the OPEFB fibre content of the bricks. Secondly, it was found that the addition of the OPEFB fibres improved the compressive strength of the bricks, and the maximum compressive strength determined in this study for bricks was with 3% fibre content. Finally, the water absorption results indicated a small increase in water absorption with the increase in the OPEFB fibre content in laterite bricks.

Keywords: Natural fibre, OPEFB fibre, laterite bricks

INTRODUCTION

Cheap building materials are necessary for the development of low cost housing in Malaysia. In particular, non-fired laterite bricks are an attractive building material because they are inexpensive to manufacture. These bricks are manufactured by sun-baking pressed earth from laterite soil that is mixed with sand and cement as composites. With earth being affordable, environment-friendly, and abundantly available, the production of blocks and bricks made from earth has been used in home construction in many countries for a long time (Binici *et al.*, 2004). Earth has been extensively used for wall construction around the world, particularly in developing countries (Ren and Kagi, 1995). Several studies have focused on improving and stabilising the development and production of these kinds of bricks and on the properties of these bricks in terms of strength, shrinkage, thermal

Received: 12 June 2009

Accepted: 9 April 2010

*Corresponding Author

conductivity, and durability of soil to meet building standards (e.g. Heathcote, 1991; Ren and Kagi, 1995; Walker, 1995; Ogunye and Boussabaine, 2002; Khedari *et al.*, 2005; Achenza and Fenu, 2006; Morel *et al.*, 2007).

The concept of using natural fibres is not new in the construction industry, as the utilisation of fibres in materials and construction can be traced back to many centuries ago. During the Egyptian times, straws or horsehairs were added to mud bricks, while straw mats were used as reinforcements in early Chinese and Japanese housing construction (Li, 2002). The application of natural fibres has been widely used in cement composites and earth blocks as construction materials for many years in developing countries due to the availability and low cost of fibres (e.g. Nilsson, 1975; Aziz *et al.*, 1984; Coutts and Ni, 1995; Aggarwal, 1995; Ghavami *et al.*, 1999; Bouhicha *et al.*, 2005; Binici *et al.*, 2005). Furthermore, several studies have proven the advantages of the use of natural fibres in soil, concrete, and cement composites; they can increase the flexural strength, post-crack load bearing capacity, impact toughness, and bending strength of these composites (e.g. Ramaswamy *et al.*, 1983; Aziz *et al.*, 1984; Swamy, 1988; Brandt, 1995; Coutts and Ni, 1995; Ghavami *et al.*, 1999; Tole[^]do Filho *et al.*, 2000). Due to their light weight, good chemical resistance (e.g. alkali in cement), corrosion resistance, and high strength-to-weight ratio, natural fibre-based composites are becoming an important composite material in the building and civil engineering fields. Therefore, this research made an attempt to turn natural fibres that are easily found in Malaysia into laterite bricks.

Oil palm production is a major agricultural industry in Malaysia. In 2007, 4.3 million hectares of land were planted with palm oil trees (MPOB, n.d.). Large quantities of palm waste, known as empty fruit bunches (EFB), are left in plantations where palm oil is produced. The abundance of oil palm EFB (OPEFB) has created crucial environmental issues, such as fouling and attraction of pests. In the past, this residue was often used as fuel to generate steam at the mills (Ma *et al.*, 1993). Unfortunately, burning these materials creates air pollution, which is prohibited by the Environment Quality Act (EQA) (1974). Nowadays, however, valuable fibre can be obtained from OPEFB, which has found its use in manufacturing board and paper.

Thus, this research investigated the physical and mechanical characteristics of laterite bricks that are reinforced with OPEFB fibres. In particular, the purpose of this research was to determine the potential and feasibility of laterite bricks that are reinforced with OPEFB fibres in increasing the added value of these products, especially in building materials. Moreover, the recycling or utilisation of solid wastes that are generated from most agro-based industries is currently very rewarding. The anxiety caused by enormous waste production, resource preservation, and material cost has focused the attention on the reuse of solid waste. Material recovery from the conversion of agricultural wastes into useful materials has not only led to environmental gains but it may also preserve natural resources. In addition, the use of waste materials is a potential alternative in the construction industry due to the increasing cost of raw materials and the continuous reduction of natural resources. Waste materials, when properly processed, have been shown as effective construction materials which readily meet design specifications (Mannan and Ganapathy, 2004). This research attempted to propose the use of these seemingly waste products as construction materials in low-cost housing as well as to encourage housing developers to invest in house construction incorporating these materials.

EXPERIMENTAL WORK

Material Used

All the materials used in this specimen were local products that had been supplied by local manufactures. The materials that were used to produce brick specimens were laterite soil, sand, cements and OPEFB fibres.

Soils

The type of soil used in this research is laterite soil, which was supplied by Majpadu Sdn. Bhd. The soil was taken from the nearby factory area and kept under roof cover to ensure that it was neither too dry nor too wet. The moisture content for the laterite soil was found to be 16.6%, as tested according to BS 1377: 1990. After sieving, the size of the soil particles was less than 2 mm in diameter, according to the manufacturer's requirements. The physical properties and chemical composition of these soils are given in Table 1.

TABLE 1
The physical properties of the soils used

Characteristics of laterite soil	Value
Specific gravity	2.66
Liquid limit (%)	63
Plastic limit (%)	32
Plasticity index (%)	31
Activity coefficient	80
Clay (%)	16
Silt (%)	37
Fine sand (%)	41
Coarse sand (%)	6

Sand

The sand used for this study was obtained from a tin mine in Puchong. The average sand particle size was below 5mm, while the moisture content recorded was 2.36%.

Cement

The cement used in this research was the ordinary Portland cement manufactured by Associated Pan Malaysia Sdn. Bhd. Cement, as specified in the Malaysian Standard specification MS 522:Part 1:2003 for concrete work.

The fibres

The OPFB fibres were obtained from the Sabutek (M) Sdn. Bhd. factory that is located in Teluk Intan, Perak. They were sun dried for one week prior to cutting them manually. The fibres were long and circular in shape. However, these fibres must be short and straight so as to ensure a quick dispersal without clinging. The fibres were then cut at an average of 25 mm length intervals. In this research, the fibres were used as additives, whereby they were added at a volume fraction of 1-5% to produce stable and improved laterite bricks. The typical physical and chemical compositions of the OPEFB fibres are presented in Tables 2 and 3.

TABLE 2
The properties of the OPEFB fibres

Properties	Value
Length (single fibre) (mm)	100- 280
Diameter (single fibre) (mm)	0.25 – 0.6
Moisture content (%)	11
Density (g/cm ³)	1.3
Breaking elongation (%)	30
Tensile strength (MPa)	21
Compression of strength (MPa)	36
Bending stress (MPa)	38

TABLE 3
Chemical composition of OPEFB fibre

Chemical composition	Value (%)
Hot water solubles	12.8
Hemi-cellulose	2.1
Lignin	25
Cellulose	59
Alkali soluble	28
Pentosans	8.7
Ash	3.2

Mix Design

The design mix proportion of all the OPEFB fibre brick specimens was 70% soil, 24% sand, and 6% cement for the matrix. All the constituent materials for the OPEFB bricks were prepared in 6 sample groups, with 20 bricks in each group, to determine the compressive strength and water absorption. Meanwhile, the total number of bricks was 120 pieces. In this study, 5 groups of the brick samples were added, with various percentages of fibre contents ranging from 1-5%, calculated based on the weight of cement. The remaining group of bricks had no fibres and served as the control samples. These control samples were used as a guide for comparison with other bricks containing fibres to determine the comparison of the physical and mechanical properties of laterite bricks. The wastage allowance was 45%, allowing for wastage in double handling (from hand mixing to pressing machine) and for error in soil weight during materials pressing. The total of the overall quantities for constituents, such as soil, sand, and cement (matrix) in the bricks, were 353, 121, and 30 kg, respectively. The total quantity of the fibres used was 750g.

Preparation of the Brick Specimens

Laterite bricks with OPEFB fibres were manufactured at the factory known as Majpadu Sdn. Bhd., which is located at Jalan Kebun, Shah Alam. The material was prepared in the laboratory of the Faculty of Architecture, Planning, and Surveying at Universiti Teknologi MARA (UiTM), before it was brought to the factory. Generally, laterite bricks are not fired but hardened from a chemical reaction and from mechanical compaction. Chemical reactions occur when the added cement reacts with the minerals in the soil. When compacted by mechanical force, soil grains and soil aggregates are bonded tightly, decreasing the pore rate of the bricks and increasing their density. As a result, water permeability and capillarity absorption are reduced. The processes involved in the OPEFB fibre brick fabrication include mixing, pressing, wrapping, and curing.

The mixing of the constituent materials

The Portland cement and OPEFB fibres were mixed beforehand in a laboratory at UiTM before they were mixed with soil and sand in the factory. The cement and fibres were weighed according to the mix design before mixing. The cement and fibres were mixed by hand to ensure an even dispersion of the fibres in the cement to prevent balling up. After that, the cement fibre mixes were packed separately in plastic bags based on the different types of fibres and brick samples. Afterwards, the cement and fibre mixtures were transported to the factory. At the factory, the cement and fibres were mixed with laterite soil and sand, according to the specified mix proportion using a hand shovel, on a piece of plywood at ground level. The mixing process took approximately 5-10 min to ensure an even dispersion of all the matrix and fibres. The production of brick samples began with the control samples, and this was followed by the mixture content with fibre.

The pressing of bricks

After mixing by hand shovel, the materials were scooped into a gunny sack, poured into the mini mixer at the pressing machine to press out the bricks and transported by conveyor. The pressure used for pressing the bricks was 9 kN/m². The pressed bricks were then moulded by using a mould size of 216 mm in length, 97 mm in width, and 68 mm in depth.

The wrapping and curing of bricks

After pressing, the bricks were stacked on timber palettes and marked according to their fibre contents and material composition. The bricks were then wrapped with a plastic film to avoid rapid drying and stored under a sheltered area for 24 h prior to spraying with water. The bricks were then stored in open air for 14 days and they were also allowed to cure for 28 days prior to use in the investigation carried out in this study.

Test Methods

All the tests were executed after the bricks had been cured for 28 days. A series of tests was conducted to determine the physical and mechanical properties of the bricks; these included dimension, density, compressive strength, and water absorption, which were conducted according to BS 3921:1985. In order to determine the dimension measurement of the bricks, deviations were taken from 10 bricks of each sample. Their length, height, and thickness were also measured. Meanwhile, the density of the brick specimens was calculated by dividing the weight with volume. The compressive strength test was carried out by imposing the bricks on a compression load until breakage to examine the variation of strengths, allowing the researchers to categorise the bricks by their strength level. Compressive strength was calculated by dividing the maximum load by the load area of the specimen according to the standards. Ten specimens from each sample group were

taken to determine their compressive strength to compute the average strength. Meanwhile, the water absorption test was carried out to determine the permeability of the bricks. The specimens were first dried in an oven for 76 h at 110°C and later cooled at room temperature before weighing. After that, the specimens were placed inside a curing tank and were boiled in water for 6 h. The specimens were removed after they had been immersed in the tank for 16 h and then weighed. The ratio of the water content to the dry mass of bricks determines the quantity of the water absorption of specimens.

RESULTS AND DISCUSSION

Brick Dimension

Brick dimension is influenced by material content and the density of the constituent materials. In this study, the average brick dimension was calculated from 10 samples for each group. The brick dimensions evaluated were length, width, depth, area, and volume. A summary of the average brick dimensions is given in Table 4. The average OPEFB fibre brick was 216.17 mm long, 97.17 mm wide and 68 mm thick. The standard deviations for all the samples were 0.41 for length, 0.41 for width, and 0 for depth. The average brick area for all the samples was 0.021 m², with a standard deviation of 0.0001 m², and the average volume was 0.00143 m³ with a standard deviation of 0.00001 m³. The standard deviation for average length, width, depth, area, and volume for bricks with the OPEFB fibre content was from 0 to 0.41. It can be summarised that bricks with OPEFB fibre had a uniform size and a surface area that is similar to fibreless bricks.

TABLE 4
The dimensions of the OPEFB fibre bricks

Type (R)	Length (mm)	Width (mm)	Depth (mm)	Area (m ²)	Volume (m ³)
R0 (0% FIBRE)	216	97	68	0.0210	0.00145
R1 (1% FIBRE)	216	97	68	0.0210	0.00142
R2 (2% FIBRE)	216	97	68	0.0210	0.00142
R3 (3% FIBRE)	216	97	68	0.0210	0.00142
R4 (4% FIBRE)	216	97	68	0.0210	0.00142
R5 (5% FIBRE)	217	98	68	0.0213	0.00143
AVERAGE	216.17	97.17	68	0.0210	0.00145
STANDARD DEVIATION	0.41	0.41	0.00	0.0001	0.00001

Brick Density

The average value for the brick density, with various levels of fibre content, is shown in *Fig. 1*. In all cases, it can be concluded that the average density of the OPEFB fibre bricks was lower than that of the control bricks. *Fig. 1* shows the decreased density of the bricks with fibres due to the fact that the OPEFB fibre replaced the heavier constituent materials, i.e. either sand or soil in laterite bricks. Meanwhile, the average density for the control bricks was 2086.29 kg/m³, whereas the average density of bricks with 1% fibre content was 2037.36 kg/m³, with a reduction of about

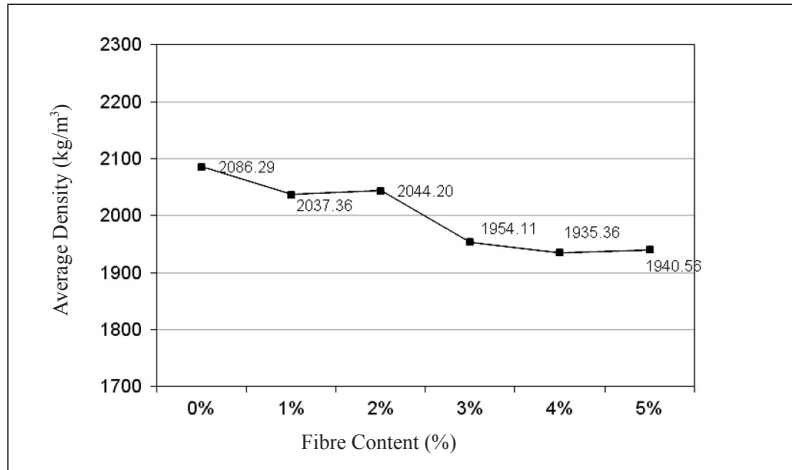


Fig. 1: Density of OPEFB fibre bricks

2.3% as compared to the density of the control bricks. There was an increase of 0.3% for the bricks with 2% fibre content as compared to the bricks with 1% fibre content. A higher reduction density was shown by the bricks with 3%, 4%, and 5% fibre contents, with a reduction in density of about 6.3%, 7.2%, and 7%, respectively, in comparison to the density of the control bricks.

Compressive Strength of the OPEFB Fibre Bricks

The compressive strength of a material determines the load-carrying capacity of that material before breakage. The compressive strength for all brick types is illustrated in Fig. 2 below.

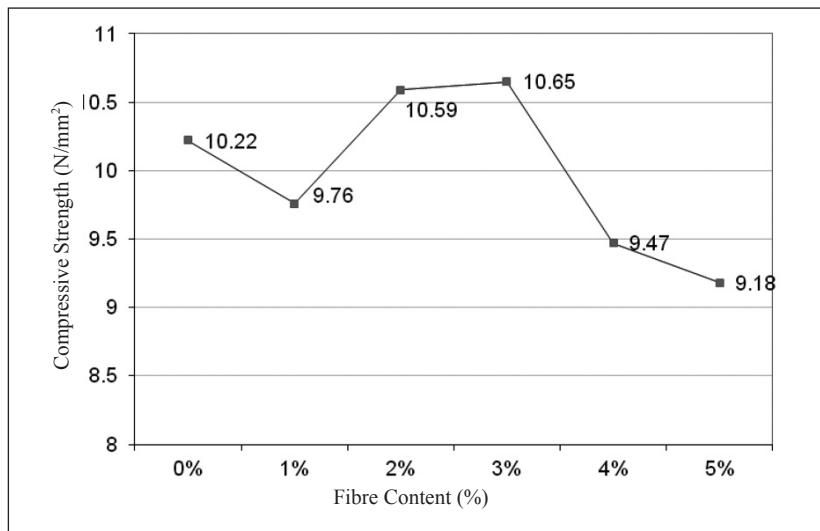


Fig. 2: The compressive strength of the OPEFB fibre bricks

As illustrated in *Fig. 2*, the compressive strength of the control bricks was 10.22N/mm². When the control was compared with the OPEFB fibre bricks with the fibre contents of 1, 4, and 5%, a slight reduction was found in strength for the bricks, that is, 9.76, 9.47, and 9.18 N/mm², respectively. However, the results for the bricks with 2 and 3% fibre contents showed that the fibres began to reinforce the bricks successfully and increase the compressive strength to 10.59 and 10.65N/mm², respectively. The increase in the compression strength for the bricks with 2% and 3% fibre contents was 3.6% and 4.2%, respectively as compared to the control bricks. Thus, it can be concluded that the optimum OPEFB fibre percentage that can successfully increase the maximum compressive strength of bricks is 3% of the fibre content. In this case, an increase in the compression strength occurs because the fibres can withstand stresses (Binici *et al.*, 2005) and successfully reinforce and hold the matrix. Based on the researchers' observation of the crack appearance of the specimens, the decrease in the compressive strength of bricks with 4% and 5% fibre contents occurred because the space occupied by the fibres acted like voids in the matrix. Such a void space could be attributed to the high volume fraction of the fibres, and the non-uniform fibre distribution tended to make fibres ball or clump together. When the fibres are not evenly distributed and orientated in the matrix, they can clump together with less matrix material in between to hold them together, creating more voids and making the bricks weak. Juárez *et al.* (2010) reported that the ultimate compressive strength of the fibre-reinforced masonry value is dependent upon the aspect ratio of the fibre. A lower fibre aspect ratio leads to a higher compressive strength in masonry pieces, but a higher addition of fibre decreases the value of compressive strength (Yetgin *et al.*, 2008).

Water Absorption

Brick density is a function of the water absorption, fibre content, and porosity. Overall, the results indicate that the density due to water absorption for bricks with OPEFB fibres is higher as compared with that for the control bricks and that it is possible for the bricks with OPEFB fibres to be more permeable to water. The relationship between water absorption and density is presented in *Fig. 3*. The higher water absorption capacity of OPEFB bricks may be attributed to the amount of water absorbed by the cellulose fibres, which is influenced by void volume and the amount of cellulose material present, and both these parameters affect density. Thus, one can expect the density to decrease and the water absorption to increase as the fibre content is increased due to the nature of the hydrophilic and low-density OPEFB fibres. At the same time, the packing of the fibres and the matrix becomes less efficient as the fibre content is increased, and causes the void volume to increase, followed by a decrease in density and an increase in water absorption (Coutts and Ni, 1995). In other words, this result is compatible with the density theory, which predicts that samples of higher original density are less likely to absorb water, and vice versa. Another result shows the same trend as the observation previously conducted by Ghavami *et al.* (1999) which indicates that the fibres absorb water and expand during mixing and drying of soil. The swelling of the fibres pushes the soil away, at least at the micro-level. At the end of the drying process, the fibres lose the moisture and shrink back almost to their original dimensions, leaving very fine voids around them.

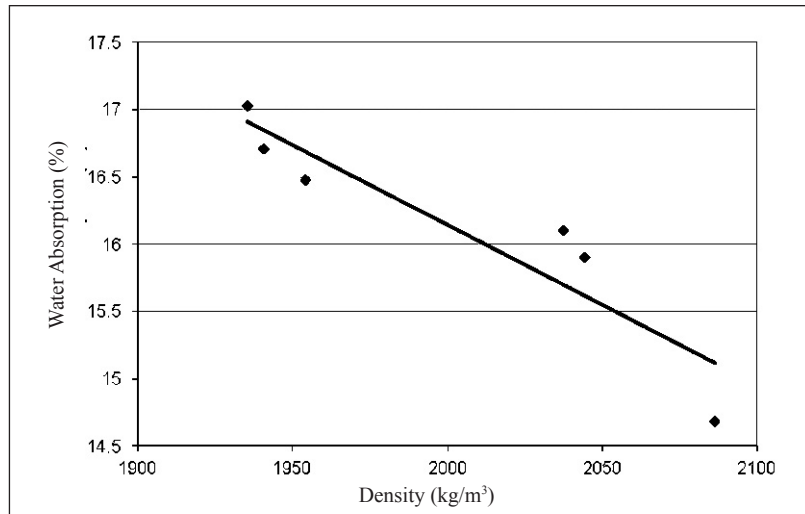


Fig. 3: The relationship between density and water absorption for the OPEFB fibre bricks

CONCLUSIONS

The following conclusions can be drawn from the findings of this research;

1. The density of the OPEFB fibre-reinforced laterite bricks decreases with the increase in fibre content. This may be due to the fibres displacing heavier constituent materials, such as cement and soil, from the laterite bricks.
2. The addition of OPEFB fibres at 3% successfully increases the compressive strength of laterite bricks. During mixing, it was observed that the OPEFB fibres at this level were well-distributed in the bricks and were able to take more loads. Moreover, they were successfully reinforced and held by the matrix, but the addition of more fibre was found to reduce the strength of bricks.
3. Bricks with OPEFB fibres have a slightly higher water permeability or absorption than fibreless bricks. In more specific, the OPEFB fibres are believed to be responsible for the absorption of more water and increase brick permeability to water.

Overall, the OPEFB fibres have the potential as reinforcement for laterite bricks. The result showed that the addition of OPEFB fibres produced lighter bricks and improved the compressive strength. However, the incorporation of fibres resulted in more permeable bricks. Hence, more study is required to determine the effect of fibre orientation in the matrix in order to understand the bond between the soil matrix and fibres better, while a study of the microstructure is also needed. Another study which can be expanded from this research is to find the special treatment of OPEFB that can improve the physical properties of the fibres so that they become less permeable to water.

REFERENCES

- Achenza, M. and Fenu, L. (2006). On earth stabilization with natural polymers for earth masonry construction. *Materials and Structures*, 39, 21–27.
- Aggarwal, L.K. (1995). Bagasses-reinforced cement composites. *Cement Concrete Composites*, 17, 107–12.
- Agopyan, V. (1988). Vegetable fibre reinforced building materials developments in Brazil and other Latin American countries. In R.N. Swamy (Ed.), *Natural fibre reinforced cement and concrete Glasgow: Blackie* (pp. 208–42). Concrete Technology and Design, 5.
- Aziz, M. A., Paramasivam, P. and Lee, S.L. (1981). Prospects for natural fibre reinforced concretes in construction. *The International Journal of Composites and Lightweight Concrete*, 3(2), 123–132.
- Binici, H., Aksogan, O. and Shah, T. (2005). Investigation of fibre reinforced mud brick as a building material. *Construction and Building Materials*, 19, 313–318.
- Bouhicha, M., Aouissi, F. and Kenai, S. (2005). Performance of composite soil reinforced with barley straw. *Cement and Concrete Composite*, 27, 617.
- Brandt, A.M. (1995). *Cement-based Composite: Materials, Mechanical Properties and Performance*. London: E & FN SPON.
- British Standards Institution. (1985). *BS 3921: 1985 Specification for Clay Bricks*. BSI, London.
- British Standards Institution. (1990). *BS 1377: Part 4: 1990 Methods of Testing Soils for Civil Engineering Purpose*. BSI, London.
- Coutts, R.S.P. and Ni, Y. (1995). Autoclaved bamboo pulp fibre reinforced cement. *Cement Concrete Composites*, 17, 99–106.
- Ghavami, K., Filho, R.D.T. and Barbosa, N.P. (1999). Behaviour of composite soil reinforced with natural fibres. *Cement Concrete Composite*, 21, 39–48.
- Heathcote, K. (1991). Compressive strength of cement stabilised pressed earth blocks. *Building Research and Information*, 19(2), 101–105.
- Khedari, J., Watsanasathaporn, P. and Hirunlabh, J. (2005). Development of fibre-based soil–cement block with low thermal conductivity. *Cement and Concrete Composites*, 27, 111–116.
- Juárez, C., Guevara, B., Valdez, P. and Durán-Herrera, A. (2010). Mechanical properties of natural fibers reinforced sustainable masonry. *Construction and Building Materials*, Article in Press, Corrected Proof.
- Law of Malaysia. (Act 127) Environmental Quality Act (EQA) 1974, *Section 29A*. Retrieved on March 20, 2009 from <http://www.doe.gov.my/v2/files/legislation/a0127.pdf>.
- Lee, S.M., Cho, D., Park, W.H., Lee, S.G., Han, S.O. and Drzal, L.T. (2005). Novel silk/poly(butylene succinate) biocomposites: The effect of short fibre content on their mechanical and thermal properties. *Composites Science and Technology*, 65, 647–657.
- Li, V.C. (2002). Large volume, high-performance applications of fibers in civil Engineering. *Journal of Applied Polymer Science*, 83(3), 660–686.
- Ma, A.N., Cheah, S.A. and Chow, M.C. (1993). Current status of palm oil processing waste management. In Yeoh *et al.* (Eds.), *Waste management in Malaysia: Current status and prospects for bioremediation*, 111–136.
- Malaysian Palm Oil Board. (n.d). Malaysian Oil Palm Statistics, 2007. Retrieved June 25, 2008 from <http://econ.mpob.gov.my/economy/annual/stat2007/Area1.1.htm>.

- Malaysian Standards. (2003). *MS 522: Part 1:2003 Portland Cement (Ordinary and Rapid-hardening): Part 1: Specification (Second revision)*. SIRIM.
- Mannan, M.A. and Ganapathy, C. (2004). Concrete from an agricultural waste-oil palm shell (OPS). *Building and Environment*, 39, 441 – 448.
- Morel, J.C., Pkla, A. and Walker, P. (2007). Compressive strength testing of compressed earth blocks. *Construction and Building Materials*, 2, 303–309.
- Nilsson, L.H. (1975). Reinforcement of concrete with sisal and other vegetable fibres. Swedish Council for Building Research, Document DIY, Stockholm, Sweden.
- Ogunye, F.O. and Boussabaine, H. (2002). Diagnosis of assessment methods for weatherability of stabilised compressed soil blocks. *Construction and Building Materials*, 16, 163–172.
- Ramaswamy, H.S., Ahuja, B.M. and Krishnamoorthy, S. (1983). Behavior of concrete reinforced with jute, coir, and bamboo fibres. *International Journal Cement Concrete Composites*, 5(1), 3–13.
- Reddy, B.V. (1998). Steam-cured stabilised soil blocks for masonry construction. *International Journal Energy and Buildings*, 29, 29–33.
- Ren K.B. and Kagi D.A. (1995). Upgrading the durability of mud bricks by impregnation. *Building and Environment*, 30, 433-440.
- Sastra, H.Y., Siregar, J.P., Sapuan, S.M., Leman, Z. and Hamdan, M.M. (2005). Flexural properties of *Arenga pinnata* fibre reinforced epoxy composites. *American Journal of Applied Sciences*, (Special Issue), 21-24.
- Swamy, R.W. (1988). *Natural Fibre Reinforced Cement and Concrete*. Glasgow, Great Britain: Bell & Bain.
- Toleˆdo Filho, R.D., Scrivener, K., England, G.L. and Ghavami, K. (2000). Durability of alkali-sensitive sisal and coconut fibres in cement mortar composites. *Cement Concrete Composite*, 22(6), 127–43.
- Yetgin, S., Cavdar, O. and avdar, A. (2008). The effects of the fiber contents on the mechanic properties of the adobes. *Construction and Building Materials*, 22(3), 222-227.
- Walker, P.J. (1995). Strength, durability and shrinkage characteristics of cement stabilised soil blocks. *Cement Concrete Composites*, 17, 301–10.

