PRODUCTION OF CONCRETE PAVEMENT BLOCK FROM DEMOLISHED FIRED CLAY BRICK WASTES

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by

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LIST OF ABBREVIATIONS

Symbols	Descriptions
ACI	American Concrete Institute
ACV	Aggregate crushing value
AIV	Aggregate impact value
Al	Aluminium
Al_2O_3	Aluminium oxide
ANOVA	Analysis of variance
ASR	Alkali-silica reaction
ASTM	American Standard Test Method
BS	British Standard
C_3A	Calcium aluminate
Ca	Calcium
Ca^{2+}	Calcium ions
$CaCO_3$	Calcium carbonate
$Ca(OH)_2$	Calcium hydroxide
$CaO.SiO_2$	Calcium silicate
$CaO.Al_2O_3$	Calcium aluminate
$CaO.Al_2O_3.Fe_2O_3$	Calcium aluminoferrite
$CaO.SiO_2.H_2O$ (C-S-H)	Calcium silicatehydrate
CA	Coarse aggregates
CCD	Central composite design
CIDB	Construction Industry Development Board
CO_2	Carbon dioxide
CSH	Calcium silicate hydrate
CWG	Coarse waste glass

DANCED	Danish Cooperation for Environment and Development
DOE	Design of Experiment/Department of Environmental
EDX	Energy disperse x-ray
ERDC	Engineer Research and Development Center
ETWB	Environment Transport and Work Bureau
FA	Fine aggregates
FCB	Fired clay bricks
Fe	Ferum
Fe_2O_3	Ferum oxide
FCBA	Fired clay brick aggregates
FCWG	Fine and coarse waste glass
FTIR	Fourier transform infra red
FWG	Fine waste glass
H_2O	Water
IBS	Industrialised Building System
ICP	Inductive coupled plasma
IS	Indian Standard
ITZ	Interfacial transition zone
K_2O	Potassium oxide
$KAl_2Si_2O_5(OH)_4$	Potassium feldspar
$KMg_3AlSi_3O_{10}(OH)_2$	Biotite
LAC	Local Authorities Cleanliness by law
LAO	Local Authorities Ordinance
LESTARI	Institut Alam Sekitar dan Pembangunan
MF	Melamine-formaldehyde

MPKj	Kajang Municipality
MSC	Modified sulphur concrete
MSW	Municipal solid wastes
NaCl	Sodium chloride
Na_2O	Sodium oxide
$NaAlSi_3O_8$	Sodium feldspar
Na_2SO_4	Sodium sulphate
NA	Natural aggregates
NGO	Non-governmental organization
NREB	National Resources and Environment Board
NREO	Natural Resources and Environment Ordinance
NRMCA	National Ready Mixed Concrete Association
O	Oxygen
OFT	One-factor-at-a-time
OPC	Ordinary Portland cement
PBT	Local authorities
PET	Poly-ethylene terephthalate
PGP	Pozzolanic glass powder
RFCB	Recycled fired clay brick
RSM	Response surface methodology
SEM	Scanning electron microscopy
Si	Silica
SiO_2	Silica oxide
SSD	Saturated surface dry
SSE	Sum of square error
TCLP	Toxicity characteristic leaching procedure

UKM	National University of Malaysia
UNEP	United Nations Environment Programmes
USEPA	United States Environmental Protection Agency
W/C	Water to cement ratio
XRD	X-ray diffraction
XRF	X-ray fluorescence

PENGHASILAN BLOK KONKRIT LALUAN AWAM DARIPADA SISA RUNTUHAN BATA TANAH LIAT TERBAKAR

ABSTRAK

Industri pembinaan adalah salah satu industri terbesar yang terlibat dalam pembangunan dan kemajuan sesebuah negara. Sisa binaan dan runtuhan (C&D) tergolong dalam sebahagian besar daripada jumlah penghasilan sisa pepejal di dunia, yang kebanyakannya dibuang di tapak pelupusan samada secara sah atau tidak. Dianggarkan sebanyak 13-30% daripada semua sisa pepejal dibuang ke tapak pelupusan di seluruh dunia, terdiri daripada sisa C&D (Bossink and Brouwers, 1996a). Masalah lain yang juga berkaitan dengan industri binaan adalah penyusutan aggregat asli dan penghasilan besar-besaran bata tanah liat terbakar dari tapak runtuhan, lalu mencetuskan masalah alam sekitar. Oleh itu, pemeliharaan alam sekitar dan pemuliharaan sumber asli yang semakin cepat menyusut menjadi inti pati kepada pembangunan lestari.

Kajian ini menekankan penggunaan sisa runtuhan bata tanah liat terbakar sebagai aggregat gantian kepada aggregat asli dalam pembuatan blok konkrit laluan awam. Kajian sifat-sifat kimia dan mineral telah dijalankan kerana ia dapat mempengaruhi prestasi blok konkrit laluan awam yang dihasilkan. Gambar mikro daripada SEM menunjukkan bahawa aggregat bata tanah liat terbakar (FCB) memiliki butir-butir yang lebih besar yang mana menunjukkan gabungan partikel-partikel. Tambahan pula, aggregat tersebut lebih berongga, berlainan jenis dan mempunyai bentuk berkelopak. Walau bagaimanapun, aggregat asli samada kasar atau halus menunjukkan bentuk berbucu tajam yang lebih baik pada persilangan

permukaan “planar” yang kasar. Bentuk kristal yang banyak dengan tekstur yang kasar dapat dilihat pada aggregat asli berbanding aggregat FCB. Analisis XRD bagi aggregat FCB menunjukkan kehadiran “quartz”, “hematite” dan “feldspar”, sementara bagi aggregat asli yang kasar dan halus, SiO_2 asli dan CaO lebih dominan, masing-masing pada $2\Theta = 26.5^{0}$ and 26.0^{0}. Unsur-unsur seperti SiO_2, Al_2O_3, Fe_2O_3 dan CaO lebih banyak dikesan dalam aggregat FCB dan asli menggunakan XRF. Blok konkrit laluan awam menggunakan aggregat FCB menunjukkan penurunan kekuatan mampatan, kekuatan lenturan, kekerasan permukaan dan modulus keanjalan apabila kadar penggantian meningkat.

Perbandingan di antara sifat-sifat blok konkrit laluan awam menggunakan kaedah satu faktor pada satu masa (OFT) dan metodologi permukaan sambutan (RSM) juga telah dijalankan. Keputusan menggunakan RSM menunjukkan kekuatan yang lebih tinggi iaitu pada 47.9 MPa, 3.9 MPa dan 35 MPa, masing-masing bagi kekuatan mampatan, kekuatan lenturan dan kekerasan permukaan, pada nisbah air berbanding simen 0.40, tempoh pengawetan selama 28 hari dan penggantian aggregat kasar 20% berbanding dengan menggunakan kaedah OFT. Sifat-sifat kimia dan mineral bagi blok konkrit laluan awam yang dibuat menunjukkan kehadiran “calcite”. Bagi kajian penyerapan secara kelompok, penyerapan Ca^{2+} menurun apabila pH, kepekatan awal Ca^{2+} dan suhu inkubasi meningkat; tetapi ia menjurus kepada peningkatan apabila masa interaksi meningkat. Malah, penyerapan Ca^{2+} lebih berpadanan kepada model isoterma Freundlich and model kinetik tertib pseudo kedua. Ini menunjukkan bahawa penyerapan Ca^{2+} ke dalam blok konkrit laluan awam didapati tidak spontan dan endotermik. Apabila terdedah kepada larutan miselium kulat reput perang, *Pycnoporous sanguineus*, didapati blok konkrit laluan awam yang menggunakan aggregat FCB tidak tahan kepada pertunbuhan kulat berbanding dengan aggregat asli.

PRODUCTION OF CONCRETE PAVEMENT BLOCK FROM DEMOLISHED FIRED CLAY BRICK WASTES

ABSTRACT

Construction industry is one of the major industries involved in country's development and modernization. Construction and demolition (C&D) wastes constitute a major portion of the total solid wastes production in the world, and most of them are disposed off legally or illegally in any landfills. It is estimated that 13-30% of all solid waste deposited in landfills worldwide comprises C&D waste (Bossink and Brouwers, 1996a). Another problem related to the construction industry is the shortage of natural aggregates and mass generation of fired clay bricks (FCB) from the demolition sites, thus creating environmental problems. Hence, preservation of the environment and conservation of the rapidly diminishing natural resources be the essence of sustainable development.

This study emphasized on the possibilities of using FCB demolition wastes as a substitute of natural aggregates for the manufacturing of concrete pavement block. The chemical and mineralogical characterizations were carried as it would influence the concrete pavement block performance. The SEM micrograph showed that FCB aggregates possessed larger grains which promoted the coalescence of particles. In fact, the aggregates were also highly porous, non-homogenous and had flaky appearance. However, the natural aggregates either, coarse or fine, showed an angular shape, with well-defined edges at the intersection of the roughly planar faces. More crystalline with rougher texture can be observed compared to the FCB aggregates. The XRD analysis of FCB aggregates showed the presence of quartz,

hematite and feldspar, while for the natural coarse and fine aggregates, pure SiO_2 and CaO are dominant at $2\Theta = 26.5^{0}$ and 26.0^{0}, respectively. The major elements constituted in FCB aggregates and natural aggregates detected using XRF were SiO_2, Al_2O_3, Fe_2O_3 and CaO. The concrete pavement blocks using FCB aggregates showed reduction in compressive strength, flexural strength, surface hardness and modulus of elasticity when the replacement level increased.

The comparison of the manufactured concrete pavement block properties using one-factor-at-a-time (OFT) method and response surface methodology (RSM) were also carried out. Results indicated that the RSM showed higher strength at 47.9 MPa, 3.9 MPa and 35 MPa for compressive strength, flexural strength and surface hardness, respectively, at water to cement ratio 0.40, curing period of 28 days, and coarse aggregates replacements of 20% as compared to that of OFT method. The chemical and mineralogical properties of manufactured pavement block showed the presence of calcite. For the batch adsorption studies, the uptake of Ca^{2+} decreased with an increase in pH, initial Ca^{2+} concentration and incubation temperature; however, it tend to increase with an increase of contact time. In fact, the adsorption of Ca^{2+} was best fitted to the Freundlich isotherm model and pseudo second-order kinetic model. Thus showing that the adsorption of Ca^{2+} into the concrete pavement block was non-spontaneous and endothermic. When exposed to the white rot fungus, *Pycnoporous sanguineus* mycelial suspension, the concrete pavement block using FCB aggregates was found to be non-resistant to fungal growth as compared to the natural aggregates.

CHAPTER ONE

INTRODUCTION

1.1 Demolition solid waste management systems in Malaysia

1.1.1 Demolition wastes: What it is?

The definitions of C&D wastes are numerous. The Canada British Columbia's Ministry of Water, Land and Air Protection (Refuse Types Defined, 2005) defined demolition wastes as solid wastes resulting from or produced by a complete or partial destruction or tearing down of buildings, parking lots, bridges, roads, sidewalks or other man-made structures acceptable to the regional waste manager. The demolition waste does not include other wastes or materials that are contained within the structure that is demolished. According to United State Environmental Protection Agency (1998) definition, the C&D wastes are waste materials produced in the process of construction, renovation or demolition of structures. These structures include buildings of all types of residential and non-residential as well as roads and bridges. Moreover, the Malaysian definition of C&D waste has been clarified by National Resources and Environment Board (NREB) and Danish Cooperation for Environment and Development (DANCED), which stated that the term C&D waste can cover a very wide range of materials. The most obvious categories are (Madsen, 2001):

- waste arising from the total or partial demolition of buildings and/or civil infrastructure
- waste arising from the construction of buildings and/or civil infrastructure

- soil, rocks and vegetation arising from land levelling, civil works and/or general foundations, and
- road planings and associated materials arising from road maintenance activities

The components of construction and demolition (C&D) wastes were typically concrete, asphalt, wood, metals, gypsum wallboard and roofing (Nittivattananon and Borongan, 2007). Zuhdi and Rupert (2004), in their studies also stated that C&D wastes are a wide mixture of concrete, bricks, stones, sand (debris) and wood, plastics, cardboard and other non-debris materials. The types of wastes are not being separated or sorted. In view of that, any definitions, discussion and information regarding demolition wastes throughout this study is presented using the term of C&D wastes.

1.1.2 Recycling

Although larger quantities of demolition wastes cannot be eliminated, the environmental impact can be reduced by making more sustainable use of such waste. This is in line with the commissioning of Agenda 21 for Sustainable Construction in Developing Countries, launched as a discussion document during the World Summit on Sustainable Development in Johannesburg in 2002. It defined sustainable development as the kind of development that needs to be pursued in order to achieve a state of sustainability. It is a continuous process of maintaining a dynamic balance between the demands of people for equity, prosperity and quality of life which is ecologically possible (Shafii *et al.*, 2006).

When speaking of sustainable construction, one could possibly think of sustaining the natural construction material that has been widely used for centuries in building houses, and all the public infrastructures. But not only natural resources that need to be conserved, but also reducing the energy consumption as well. The increased demand from the global population has caused a huge number of natural resources and even energy to be consumed, in order to meet the requirement. Consumption is one thing but generation of wastes is another matter. The more we build, the more we generated wastes. Due to this fact, recycling is seen to be one of the solutions that could precisely be used in order to minimize the demolition wastes being thrown away. Debieb and Kenai (2007) stated that recycling and reuse of building rubble present interesting possibilities for economy on waste disposal sites and conservation of natural resources.

The use of recycled aggregates also saved our natural resources and dumping spaces, and helped to maintain a clean environment (Batayneh *et al.,* 2006). Besides, as reported by Begum *et al.,* (2006) the estimated net benefit of reuse and recycling of waste materials was about 2.5% of the total project budget. With regard to this, the Malaysian government can introduce higher charges for C&D waste disposal, which may reduce the amount of construction waste disposed off at landfills, and motivate contractors to separate the wastes, as well as, to reduce, reuse and recycle. With such higher disposal charges, the Construction Industry Development Board (CIDB) could also provide additional incentives to encourage waste sorting, reducing, reusing, and recycling, thereby enhancing waste management practices among contractors (Begum *et al.*, 2006).

1.1.3 Policies and laws

In Malaysia, there is legislation to control construction industry. C&D waste is under the responsibilities of the local authorities within the Local Government Act of 1976 (Act 171). Every municipality has their own small legislations to administer the C&D waste management. The Institut Alam Sekitar dan Pembangunan (LESTARI), Universiti Kebangsaan Malaysia (UKM) has already studied the C&D waste management of Kajang Municipality (MPKj). The disposal of C&D waste in MPKj area was managed by the Alam Flora Sdn. Bhd. and some private contractors. The responsibility of MPKj is to control and monitor the construction and disposal contractors so that they can follow and obey the specified regulations and acts. LESTARI also made surveys on the general profile of contractors, the willingness to pay in order to improve the C&D waste management, and also factors that determined the amount of payment that they are willing to pay (Pereira *et al.,* 2005). Nittivattananon and Borongan (2007) reported that Malaysia is one of the Asian countries that has implemented the G8 Action Plan on Science and Technology for Sustainable Development: Reduce, Reuse, and Recycle ("3R") Action Plan in C&D waste management.

In the case of our country, Malaysia, a few regulating bodies' in some municipalities or cities which deal with construction waste management enforcement are the Local Authorities Ordinance (LAO), the Local Authorities Cleanliness by law (LAC), and the Natural Resources and Environment Ordinance (NREO). Existing regulations are concerned with waste flow generation, transportation and disposal (Lau and Whyte, 2007). Different municipalities in Malaysia has numbers of provisions that are available to regulate the management of construction wastes.

According to Nitivattananon and Borongan (2008), existing provisions are currently not put in place due to the fact that the C&D waste management is yet informal. Furthermore in 2007, the Department of National Solid Waste Management under the Ministry of Housing and Local Government is in the process of formulating policies in addressing to C&D waste. C&D waste is categorized as another unit of waste, and not included in the municipal waste category (personal communication with officer at Ministry of Housing and Local Government, Malaysia). Hence, a formal national regulation on C&D waste management relative to 3R is still the process of development in Malaysia.

1.1.4 Stakeholders and technologies

Nittivattananon and Borongan (2008) stated that the Malaysian stakeholders participation on C&D waste management includes developers, contractors, construction industry, research institutes, local authority and government and NGOs. Large contractors gave some awards for 3R to the Project managers, site supervisors and also workers. Moreover, the construction waste disposal charge in Bangi, Selangor was in average of RM 50 or US$ 15 per tonne. In 2007, Malaysia has sanitary landfill for C&D wastes such as in Bukit Tagar and Air Hitam in Selangor, however, the status of the facility is still weak as it needs participation from the construction practitioner. Table 1.1 summarized the current status of C&D waste management in Malaysia.

Table 1.1: Current status of C&D waste management in Malaysia (Nitivattananon and Barongan, 2008)

Management Aspect	Information Base*	3R Principle			Waste Disposal	Monitoring
		Reduce	Reuse	Recycle		
Policies, regulations and laws	F	3	2	3	2	2
Management Practices	F	3	1	2	2	3
Stakeholders' Participation	P	U	2	3	2	3
Technologies	P	U	1	2	2	2

Notes:
**Information base: F = fair; P = poor*
Status rating: 1 = High; 2 = Moderate; 3 = Relatively low; U = Unknown

1.2 Demolition solid wastes disposal system

In general, demolition solid wastes are bulky, heavy, and mostly unsuitable for disposal by incineration or composting (Nittivattananon and Borongan, 2008). It also created waste management problems in most places especially in undeveloped countries. Begum *et al.,* (2009) reported that the majority of contractors (65%) who were responsible for C&D waste disposal disposed their waste at landfills, while about 9% of the contractors disposed off their waste at illegal dumpsites, nearby construction sites and other locations. Zuhdi and Rupert (2004) previously stated that C&D wastes in Malaysia were disposed off mainly at legal and illegal dumpsites. Such wastes are not considered as hazardous or toxic waste and thus, its disposal does not require special landfill preparations. However, in the Malaysian construction industry, data is not readily available on the current structure of the C&D waste flows by the source of generation, type of waste, intermediate and final disposal, and the amount of C&D waste reduced at source, reused or recycled on-site or off-site.

1.3 Problem statement

Preventing and managing wastes are the heart of sustainable development. Generally, C&D waste is a growing problem in many countries especially the urban development which is believed to be the one leads to the increase in C&D waste. It became a serious environmental problem in many large cities in the world (Ferguson *et al.,* 1995; Wong and Tanner, 1997; Shen *et al.,* 2000, Smallwood, 2000; Chen *et al.,* 2002; Shen and Tam, 2002). In fact, the quantities of C&D wastes kept on increasing with the increased use of land for new construction, renovation, and demolition of old structures to build a new one. Lack of consideration given to waste reduction during planning and design stage leads to failure of minimizing the generation of waste. The excessive wastage of raw materials, improper waste management and low awareness of the need for waste reduction are common in the local construction site (Begum *et al.,* 2006) which contributed to the generation of C&D waste. Skoyles and Skoyles (1987) demonstrated that the C&D wastes have become a burden to clients due to the costs of such wastes. As a result, the numbers of new landfill sites designated for C&D wastes as well as those uncontrolled or unregulated sites were increasing and old landfills were almost reaching their maximum capacity (Kartam *et al.,* 2004).

Aggregates, which were the most important constituent used in concrete block making, were also a vital material for the construction industry and led to quarry of natural materials used for the production of concrete block. The global demand for construction aggregates may exceed 26 billion tones by 2011 (Fredonia, 2007). Leading this demand, are the single user: China (25%), EU (12%) and the USA (10%) (Parekh and Modhera, 2011). Natural resources are something that cannot be renewable. Their utilization is categorized as one out of four basic problems which are more or less unsolved today. In a world with limited resources and serious environmental impacts, it is obvious that a more sustainable life style would be more and more important (Ljungberg, 2007). Thus, indicating a growing concern for protecting the environment and a need to preserve the natural resources (such as aggregate) by using alternative materials such as recycled aggregates (Ling and Hasanan, 2006).

The use of Industrialised Building System (IBS) was seen as an alternative way, and has advantages such as to reduce the material wastage on the construction site. In fact, the impact of natural disaster such as tsunami towards the generation of demolition wastes also has became an important issue to be discussed nowadays. The assessment made by United Nations Environment Programmes (UNEP, 2005a) found out that the Indian Ocean earthquake and tsunami that occurred on 26th of December 2004 (the "Tsunami") not only severely affected the coastal areas of the Indonesian province of Aceh, Sri Lanka, Thailand, Southern India, the Maldives, Malaysia, and Myanmar, taking over 250,000 lives, and leaving millions homeless or displaced, but also causing enormous destruction to infra-structures and suffering. Much of these wastes were dispersed over the affected islands and dumpsites were completely washed into the sea or were dumped improperly due to lack of adequate waste disposal facilities. Consequently, the wastes contaminated the groundwater supplies and the marine environment. It can be safely assumed that similar problems occurred on all of the impacted islands. A rough order calculation for the city of Banda Acheh, Indonesia alone estimates the volume of waste at between 7 to 10 million cubic metres (UNEP, 2005b).

Given these scenarios, most of countries today are looking forward to recycle and reuse the C&D wastes, especially the earth-based materials such as fired clay bricks, in order to reduce the capacity of such wastes from being dumped in landfill site. This will help each country to preserve the world's environment and also minimize the construction cost. The problem of wastes, especially demolition wastes, should be given higher priority in the country as much as given to the construction wastes. Thus, this study was carried out to investigate the possibility of producing concrete pavement block using clay based demolition waste materials substituting the natural aggregates.

1.4 Research objectives

The main objective of this study is to replace the natural aggregates with fired clay brick aggregates for the production of concrete pavement block. The measurable objectives of this project are as follows:

1. To investigate the chemical, mineralogical and physical properties of fired clay-based wastes.

2. To develop an optimum mixing proportion by replacing the natural aggregates with fired clay brick aggregates for the manufacturing of concrete pavement block using one-factor-at-a-time method and Design of Experiment (DOE).

3. To study the chemical and mineralogical properties of the manufactured concrete pavement block.

4. To study the adsorption of Ca^{2+} into the manufactured concrete pavement block.

5. To study the resistance of manufactured concrete pavement block against fungal growth.

1.5 Thesis organization

This thesis structure is organized into six main chapters and each chapter is described based on the sequence of this research.

Chapter 1 introduces the demolition solid waste management systems in Malaysia. A brief discussion on the definitions of demolition wastes, recycling, policies and laws and stakeholders and technologies of demolition solid waste management are also presented. The demolition solid waste disposal systems in Malaysia is also highlighted. This chapter also presents the problem statement, research objectives and thesis organization.

Chapter 2 reviews the previous findings. The first section discusses on the global overview on construction and demolition wastes. The next section introduces concrete pavement block. An overview with a brief history of fired clay brick initiates in the next section. The description of adsorption of calcium ions and corrosion, adsorption isotherms, adsorption kinetics and adsorption thermodynamics are also discussed in section three. Finally, the response surface methodology and optimization is presented in section four.

Chapter 3 covers the methodology for the experimental work carried out in this research. This chapter presents in detail the materials and chemicals used throughout the present study. The subsequent sections gave detailed experimental procedures which includes the overall experimental flowchart, concrete pavement block manufacturing, batch adsorption studies, fungal resistance test and as well as design of experiments and optimization of the manufactured pavement block.

Chapter 4 presents the experimental results together with the discussion. The detail explanations of the results have been divided into six main sections. In the first section, the physical properties and characteristics of fired clay brick waste aggregates and natural aggregates were studied. The second section discussed the properties of the manufactured pavement block with fired clay brick aggregates and natural aggregates using one-factor-at-a-time (OFT) method. Section three presents the manufactured pavement block using response surface methodology. Comparison of mixing proportion between response surface methodology (RSM) and one-factor-at-a-time (OFT) method is presented in the following section. Batch adsorption studies of Ca^{2+} on the manufactured pavement blocks are elaborated in section five whereas section six highlighted the fungal resistance studies. Finally, the cost comparison on concrete pavement block is also included.

Chapter 5 gives the conclusions and recommendations of the thesis for future research.

CHAPTER TWO

LITERATURE REVIEW

2.3 Global overview on construction and demolition (C&D) wastes

The amount of wastes generated by the construction and demolition activities are substantial (Couto and Couto, 2010). The accumulation of such wastes have become a worldwide problem. Fishbein *et al.*, (1998) reported that C&D debris frequently made up 10–30% of the wastes received at many landfill sites around the world. It is estimated that 13-30% of all solid waste deposited in landfills worldwide comprised of C&D wastes (Bossink and Brouwers, 1996a) with a 1:2 ratio of construction to demolition wastes (Bossink *et al.*, 1996b). According to Madsen (2001), in 1997 C&D wastes accounted for 27 % of the total waste amounts in Denmark (by weight). Even, in some countries the volume of C&D wastes going to landfill exceeds the total amount of household wastes. From USEPA (1998), an estimation of 123 million metric tons of building-related C&D wastes were generated in 1996. Building and demolition wastes accounted for 48 percent of the waste stream, or 65 million tons per year; renovations account for 44 percent, or 60 million tons per year; and 8 percent, or 11 million tons per year, is generated at the construction sites. Later, Al Masha'an and Mahrous (1999) stated that in developing countries, demolition wastes comprised of 20 to 30% of the total annual solid wastes. Surveys conducted in several countries found that the C&D wastes are as high as 20% to 30% of the total wastes entering the landfills throughout the world (Bossink and Brouwers, 1996a). Moreover, the weight of the generated demolition wastes are more than twice the weight of the generated construction waste (Couto and Couto, 2010).

Asian countries are facing similar scenarios on the C&D waste problem. Nitivattananon and Borongan (2008), in their studies stated that parallel to rapid economic growth and urbanization in Asia, environmental impacts from C&D wastes are increasingly becoming a major issue in urban waste management. It gave negative effects on the environment due to the mass generation of C&D wastes. According to Ong *et al.*, (2009), the average amount of demolition wastes generated in Singapore is estimated to be 2 million tons per year (based on construction demand of S$17 billion), of which the concrete wastes made up about 70% (or 1.4 million tons) of the demolition waste. The C&D wastes sometimes constitute between 20 and 25% of municipal solid wastes (MSW) in Taiwan (Environmental Protection Administration, 1999). According to Asolekar (2004), in India, about 14.5 metric tons of solid wastes are generated annually from the construction industries, which include wasted sand, gravel, bitumen, bricks, and masonry concrete. In Korea, it is advised to use/apply recycled aggregates in concrete structures, since a huge amount of construction wastes were generated, accounting for 2,000,000 tons yearly, including mainly the concrete fragments from the demolition of dilapidated housing (KICT, 2006).

In recent studies conducted regarding the breakdown of wastes in the central and southern regions of Malaysia, 28.34% of the total wastes generated was contributed by construction and industrial waste-stream (Begum *et al*., 2006). According to the Natural Resources and Environmental Board (NREB, 2005), there are a total of 45 existing landfills in Sarawak, 40 of which were visited by the NREB regularly. The total area allocated for the dumping of municipal solid wastes are around 80 hectares, at which about 370,000 metric tonnes of solid wastes are disposed at these sites per annum. The waste flow of C&D waste generated in Kuching is shown in Figure 2.1.

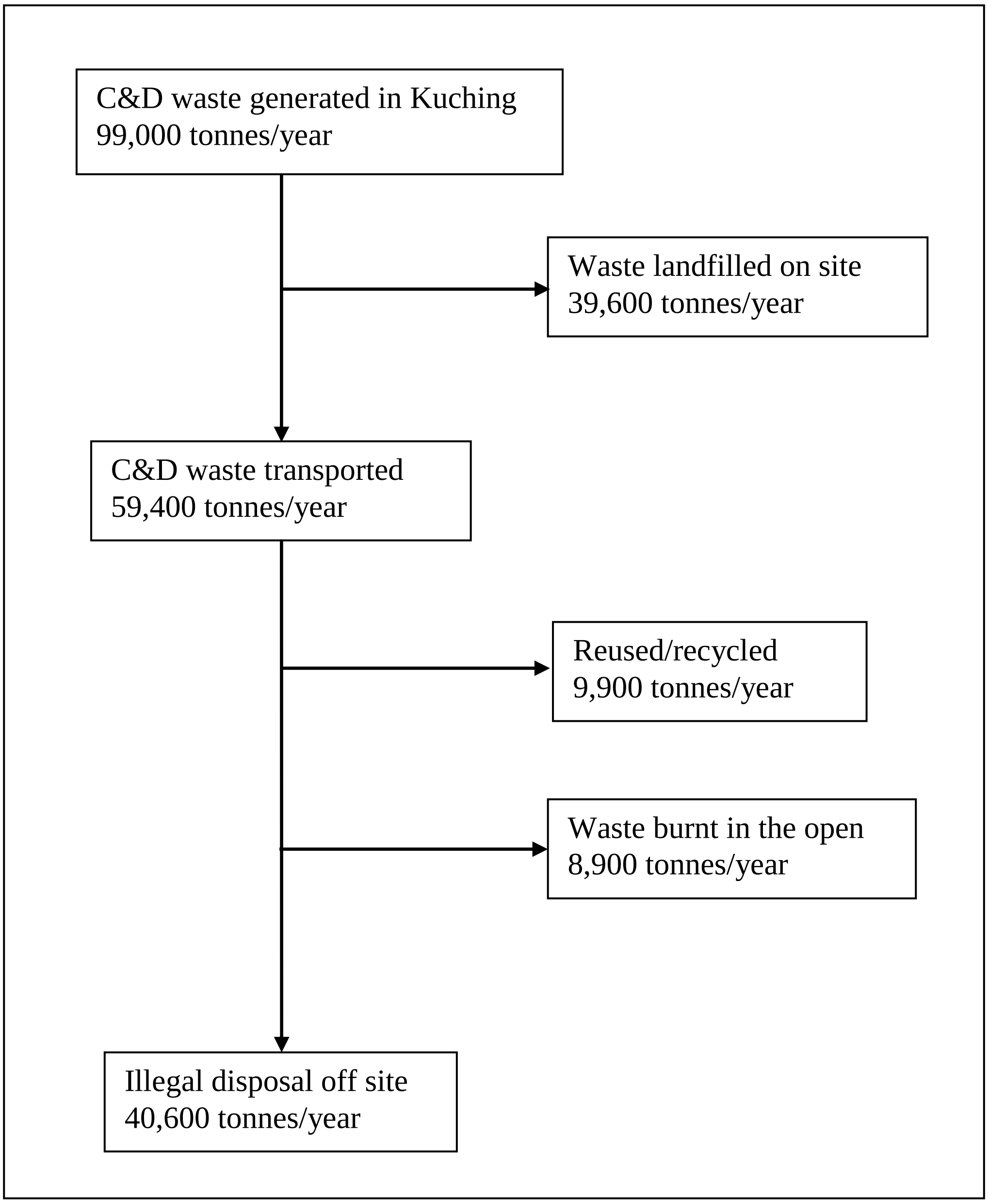

Figure 2.1: The waste flow of C&D waste generated in Kuching (Source: Tang *et al.*, 2003)

Figure 2.2 shows that C&D wastes accounted for 585.4 tonnes or 0.4 percent of the total solid wastes disposed at Pulau Burung sanitary landfill within the 9 months studied period. Although the C&D wastes was the second smallest portion of the total solid waste disposed, consideration for effective and efficient management are required to reduce or minimize such wastes as the C&D waste is bulky, cannot be compacted and will take up permanent space in the landfill. Figure 2.3 displays the average composition of C&D waste materials disposed at the Pulau Burung sanitary landfill (Asaari *et al.*, 2004). The estimated amount of C&D wastes for the Klang Valley is approximately 1.6 million tonnes per year. The majority of these C&D wastes originated from private renovation and demolition projects (Zuhdi and Rupert, 2004).

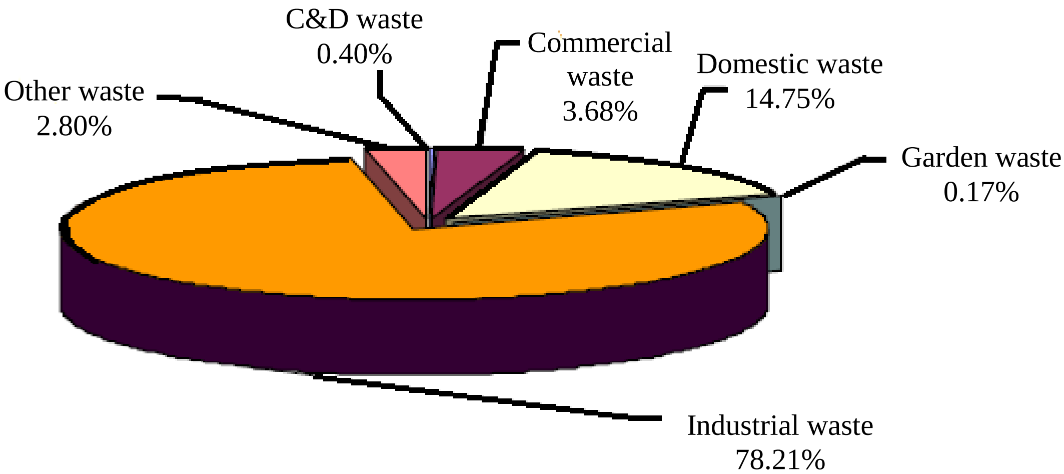

Figure 2.2: Waste disposal at Pulau Burung sanitary landfill (Asaari *et al.*, 2004)

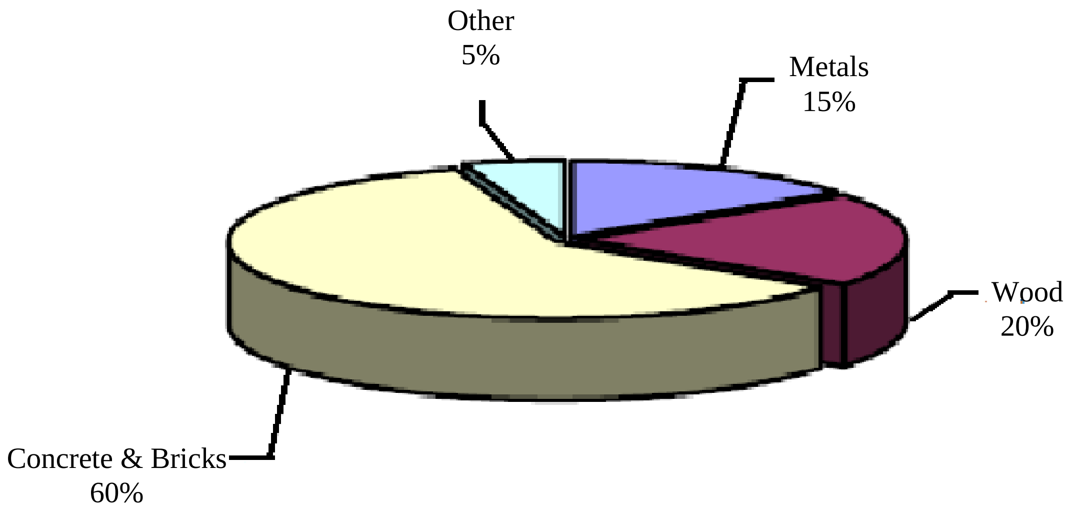

Figure 2.3: C&D composition at Pulau Burung sanitary landfill (% by weight) (Asaari *et al.*, 2004)

However, it has been very difficult to obtain records and data on this kind of waste since C&D waste are dumped both legally and illegally, and in different places such as near road sides, illegal dumpsites from time to time in proportion to the development of the state (Asaari *et al.*, 2004). Goh (2007), in his studies stated that Malaysia is facing serious landfill problems. These include shortage of landfills, overused landfills, poor management, leachate and the cost of disposal. As reported by the Minister of Housing and Local Government in their bulletin of 2000, 80% of the country's 230 landfills has only two more years of life. By 2002, the number of landfills dropped to 170 and at the beginning of 2004, there were still 170 registered disposal sites. Therefore, the waste management plans should be created, arranged and authorized efficiently in order to ensure the successful of reducing the C&D wastes impacted to the country. According to Fatta *et al.,* (2004), waste minimization and effective waste management are considered as the basic principles in environmental legislations and strategies in some countries.

C&D waste disposal is difficult with regard to the difficulty in finding new landfill areas. Besides that, the disposal of hazardous solid wastes in landfills was a major environmental issue worldwide because heavy metals present in waste could leached into the surrounding soil and groundwater, posing a threat to the environment and to human health (Amal *et al.*, 2005). In view of that, a Toxicity Characteristic Leaching Procedure (TCLP) test need to be performed to the solid wastes in order to determine if the material is hazardous. If it is hazardous, the material must be managed accordingly. If the waste were not hazardous, the grit of solid wastes must be disposed off properly (Townsend, 1997). Although the TCLP test is principally used to determine the hazardous characteristics, it is occasionally utilized to determine the impact of waste on groundwater even when the wastes were stored or disposed in non-landfill conditions (Townsend and Brantley, 1998). The TCLP test established concentration limits for substances beyond which a material is classified as hazardous wastes (Inyang, 2003). Wang *et al.,* (2008) reported that the TCLP test of lead with concentrations in the TCLP extracts of less than 5mg/L, are not considered to be hazardous materials. Therefore, recycled aggregates are allowed to be use in concrete block manufacturing.

2.4 Concrete pavement block

Concrete pavement block or is also known as interlocking concrete block pavement or concrete interlocking paving blocks, by some researchers (Nur Izzi *et al.,* 2006; Brozovsky *et al.,* 2005) had become an alternative in road construction. During the 1970s, the concrete pavement block was introduced to Britain, Canada, United States, Australia, New Zealand and Japan. Subsequently, the use of concrete pavement block spread to the Middle East and Asia. Most of these regions, especially North America, have experienced a sustained growth in the paving market (Shackel, 2003). Interlocking concrete block pavement had several advantages from physical aspects and esthetical value (Nur Izzi *et al.,* 2006). Concrete pavement block was also versatile, aesthetically attractive, functional, cost effective and requires little or no maintenance if correctly manufactured and laid (Cement and Concrete Institute, 2009).

In Malaysia, concrete pavement block was used around the 1980s, at road junctions, bus stops, car parks and recreational parks (New Straits Times, 1997). The testing conducted around the world demonstrated that concrete pavement block was unique in many ways. It did not only respond to traffic in a manner that was quite unlike asphalt or rigid concrete but it behaved differently from other forms of segmental paving such as brick and stone. In particular, it tended to become progressively stiffer and stronger under traffic load repetition and can perform satisfactorily in respect of rutting whilst simultaneously exhibiting levels of resilient deflection that were very much higher than those that would be tolerated in asphalt pavement (Shackel, 2003).

2.4.1 Materials to produce concrete pavement block

Traditional cement pavers mainly contain Portland cement, and both coarse and fine aggregates (Wattanasiriwech *et al.,* 2009). Different percentages of cement, water, fine aggregates and coarse aggregates were combined in order to produce concrete of the required workability and strength (Batayneh *et al.,* 2006).

2.2.1 (a) Cement

Cement is an important material in concrete production besides aggregates and water. Cements used for making concrete were finely ground powders and all having the important property that when mixed with water a chemical reaction (hydration) took place which produced a very hard and strong binding medium for the aggregate particles (Jackson and Dhir, 1996). It functioned like a binder to the aggregates. The raw materials used in the manufacture of Portland cement consist mainly of lime, silica, alumina and iron oxide (Neville *et al.,* 1995).

2.2.1 (b) Aggregates

Some of the aggregate properties which affect the workability of concrete pavement block are maximum particle size, particle shape, surface texture, and grading or particle size distribution (Lydon *et al.*, 1982). Neville *et al.*, (1995) suggested that to manufacture good quality of concrete, the aggregate must be at least in two size groups, the main division being between fine aggregate not larger than 5 mm and coarse aggregate which is at least 5 mm in size. Many properties of the aggregate depended entirely on the properties of the parent rock in term of chemical and mineral composition, petrology character, specific gravity, hardness, strength, physical and chemical stability, pore structure and color. However, particle shape and size, surface texture and absorption were mostly possessed by the aggregate but not the parent rock. All these were said to have considerable influenced on the quality of the concrete, either fresh or in the hardened state.

The aggregate whose properties was satisfactory will not necessarily result in good quality of concrete, so the criterion of performance in concrete has to be used as well. The external characteristics of aggregate was also important especially the particle shape and surface texture. Table 2.1 summarizes the particle shape classification according to British Standard (BS 812: Part 1: 1975). In the case of crushed aggregate, the particle shape depends not only on the nature of the parent material but also on the type of crusher and its reduction ratio, i.e. the ratio of the size of material fed into the crusher to the size of the finished product. The shape of aggregate particles influences the mix properties which explained that angular particles requiring more water for a given workability.

Table 2.1: Particle shape classification of BS 812: Part 1: 1975 with examples (Neville *et al.*, 1995)

Classification	Description	Examples
Rounded	Fully water-worn or completely shaped by attrition	River or seashore gravel; desert, seashore and wind-blown sand
Irregular	Naturally irregular, or partly shaped by attrition and having rounded edges	Other gravels; land or dug flint
Flaky	Material of which the thickness is small relative to the other two dimensions	Laminated rock
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces	Crushed rock of all types; talus; crushed slag
Elongated	Material, usually angular in which the length is considerably larger than the other two dimensions	-
Flaky and elongated	Material having the length considerably larger than width, and the width considerably larger than the thickness	-

2.2.1 (c) Water

In order to obtain a good workability of concrete mixture, the quantity of water content in concrete production should be proportion to the cement and aggregates used. Basically, the water content was evaluated from the water to cement ratio of concrete mixture. The amount of water mix with the aggregates and cement used should give a good fresh state of concrete mixture with the required slump value. It should be noted that different types of aggregates used in concrete production required different amount of water content. Therefore, it is advisable to select suitable water content so that the required workability can be obtained (Lydon *et al.*, 1982).

2.2.2 Properties of concrete pavement block

Concrete pavement block can be defined as an individual unit with small sizes of not more than 0.09 m^2 and these concrete blocks interlocked one another when they are arranged. The concrete blocks can be arranged with various arrangements such as basket weave, stretcher bond and herringbond (Rada *et al.*, 1990) as shown in Figure 2.4. Cement and Concrete Institute (2009) has highlighted several properties of concrete paving block. The blocks should meet structural requirements for paving (specified in terms of block compressive strength and/or tensile splitting strength), durable and should be able to withstand abrasion, impact and chemical attack, should be of uniform dimensions to facilitate correct and easy placing and ensure good rideability and also aesthetically attractive.

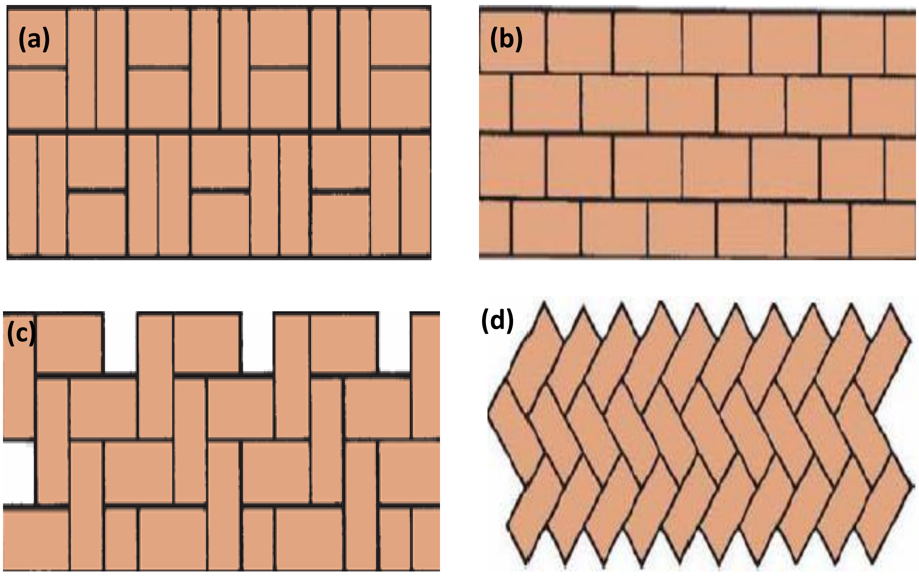

Figure 2.4: Concrete pavement blocks arranged in (a) basket weave (b) stretcher bond (c) herringbone in 90^0 angle, and (d) herringbone in 45^0 angle

Strength requirement of concrete paving block used in traffic areas has been reported by Poon and Chan (2006). As prescribed by the British Standard (BS 6717), the tensile splitting strength should be at or more than 3.9 MPa and compressive strength prescribed by ASTM C936 is at or more than 55.2 MPa. The specification of concrete paving block should comply with certain tolerances, and have a compressive strength of 25 MPa, for lightly trafficked situations, or 35 MPa, for more severe conditions or where a wheel load greater than 30 kN is encountered. The latest standard specifies a tensile splitting strength of 2.2 MPa for light traffic and 2.8 MPa for heavy traffic (Cement and Concrete Institute, 2009).

2.2.3 Use of concrete pavement block

Normally, concrete pavement blocks are used for a wide range of traffic pavements. Nur Izzi *et al.*, (2006) reported that the interlocking concrete block pavements were not only used in pedestrian areas but also used in road areas. The asphalt pavement was no longer could withstand the increasing of traffic load, heavy trucks and lorries, new design of axle, tyres pressure and the weather factor. Besides that, the use of concrete block pavement became an option when comes to harbour areas, airports, bas stations and car parks which involved of high traffic load. According to Anderton (1991) paving blocks have been recognized for their potential in heavy-load pavement applications. Concrete block pavements have been used in low-speed, heavily-trafficked urban streets, port facility loading terminals and airfield taxiways.

2.2.4 Concrete pavement block manufacturing using recycled aggregates

Many research papers have reported on modifications of paver components in order to:- (i) improve properties of the pavers, (ii) reduce the material cost or (iii) utilize waste materials for sustainable construction (Wattanasiriwech *et al.,* 2009). Initially, recycling of demolition waste was first carried out after the Second World War in Germany (Khalaf *et al.,* 2004). Since then, research work carried out in several countries has demonstrated sufficient promise for developing use of construction waste as constituent in new concrete. Table 2.2 summarizes the types of aggregates used in concrete pavement blocks production.

Table 2.2: Types of aggregates used in concrete pavement blocks production

Type of recycled aggregates	**References**
(a) Concrete aggregates	Poon *et al.,* (2002), Kutegeza *et al,* (2004), Levy and Helene (2004), Batayneh *et al.,* (2006), Kim *et al.,* (2007), Tabsh and Abdelfatah (2009), Evangelista and de Brito (2010)
(b) Ceramic tiles aggregates	Khaloo *et al.,* (1995), Ay and Unal (2000), Brito *et al.,* (2005), Senthamarai and Manoharan (2005), Mustafa *et al.,* (2006), Poon and Chan (2007), Pacheco-Torgal and Jalali (2009), Chan (2010)
(c) Glass aggregates	Rindl *et al.,* (1998), Park *et al.,* (2004), Shayan and Xu (2004), Topcu and Canbaz (2004), Batayneh *et al.,* (2006), Terro (2006), Taha and Nounu (2009), Tuhgut and Yahlizade (2009)

Table 2.2: Continued.

Type of recycled aggregates	References
(d) Timber/wood aggregates	Stahl *et al.*, (2002), Naik and Kraus (2003), Reis (2006)
(e) Plastic aggregates	Al Nageim *et al.*, (2004), Boutemeur *et al.*, (2004), Hassani *et al.*, (2005), Batayneh *et al.*, (2006), Dweik *et al.*, (2008), Siddique *et al.*, (2008)

2.3 Fired clay brick (FCB) materials

Fired clay bricks (FCB) have been developed since the Warring states (475-221 B.C.) in China and being famous for "Qin Brick and Han Tile" in the world (Li *et al.*, 1998). The production of FCB was normally mixed with water and sand and the mixture was then used in an extrusion machine to shape the blocks. Subsequently, the bricks were heat treated in ovens for a period of one day at temperatures of approximately 600 ^{0}C. The blocks were then dried in air (Calabria *et al.*, 2008). A study from Boke *et al.*, (2006) revealed that the raw materials used in the manufacture of bricks were natural clays containing quartz, feldspar and other accessory minerals. The function of clay minerals was to provide plasticity while feldspar acted as a flux to decrease the melting point and quartz was a space filler in the bricks. Jackson and Dhir (1996) explained that clay bricks was made by shaping suitable clays and shale to units of standard size which were then fired to a temperature in the range 900 to 1200 ^{0}C. The size of building brick according to BS 3921 is 225 mm x 112.5 mm x 75 mm. It should be noted that the term 'fireclay' suggests the ability to withstand heat. For high refractoriness, the alumina content should be high (approaching 30-40%) and lower alkali content (less than 1%). Fireclays have been subjected to considerable pressure because of the depth of burial, causing them to be hard and compacted (Worral, 1986).

2.3.1 Properties of FCB materials

2.3.1 (a) Physical/ Mechanical

The FCB can be classified depending on the baking temperature and the characteristic color of it (Custodio-Garcia *et al.,* 2005):

Type A: high-temperature baking (blackish or dark red)

Type B: medium-temperature baking (red)

Type C: low-temperature baking (orange or cram-colored)

The others physical properties of FCB could be observed through scanning electron microscopy (SEM). Report from Calabria *et al.,* (2008) stated the presence of two microstructural features in FCB which showed a lamellar feature with impregnated crystals on the surface and larger grains also can be observed to the rest of the specimen. Porosity was reported uniformly distributed throughout the sample. The surface of FCB suggested a more compacted structure which came from the stronger bonds between grains formed during firing. Furthermore, the FCB was also a porous material and was said to be hydrophilic.

Jackson and Dhir (1996) stated that the volume fraction porosity of clay bricks varied greatly from about 1 per cent to at least 50 per cent. The pores had dimensions typically about 1 to 10 μm. There appeared to be almost no micropores