PERFORMANCE OF CEMENT STABILISED PEAT BRICKS

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ABSTRACT

The popularity of low cost, lightweight and environmentally affable masonry unit in building industry carries the need to investigate more flexible and adaptable brick components as well as to retain the requirements of building standards. This thesis presents a study on peat used in building materials, as well as the effect of peat on bricks with regard to durability and thermal transmittance.

The physical and mechanical properties of peat added bricks are discusses on this study. In this regard, it considered influence of peat on the brick composites and their role in various types of constructional applications. The durability of peat added bricks was tested using a modified Spray Test in order to examine performance of competent strategies to counter deterioration due to wind-driven rain erosion. The thermo-mechanical performances of peat added bricks examined here are intended to fill the gap of knowledge to some extend in bricks production. A comparative analysis was conducted between sand-brick and peat-brick in order to study the effect of peat inclusion on the thermal properties. Thermal test was performed using a dynamic adiabatic-box technique. The time–temperature data of the test samples were compared for the test samples.

It was found that the compressive strength, splitting tensile stress, flexural strength, unit weight, ultrasonic pulse velocity (UPV) were significantly reduced and the water absorption was increased with percentage wise replacement of peat as aggregate in the samples. The maximum 20% of (mass) peat content can satisfy the relevant international standards. The experimental values illustrated that, the 54% volumetric replacement with peat did not exhibit any sudden brittle fracture, even beyond the ultimate loads.

Erosion resistance of peat added brick was found greatly influenced by the percentage of peat content. An increase of 10% in peat content leads to a sharp negative change in erosion depth. This is followed by a growth of 65% in erosion rate. The specimens with maximum of 20% peat had better erosion resistance but the brick with 25% peat required good surface finish.

Thermal test results indicate that inclusion of peat into sand-cement mixture decreases the thermal conductivity i.e. thermal insulation performance improves in the range of 2.2% to 6.2% after inclusion of peat and depends on the amount of peat content.

From this study, it can be concluded that the physical and mechanical properties, durability and thermal performance of the peat added bricks greatly depend on the peat content. The application of peat and sand as efficient brick substance indeed has a potential to be used in wall and as an alternative building material.

ABSTRAK

Populariti batu-bata kos rendah, ringan dan mesra alam dalam industri memerlukan penyelidikan dengan tujuan pengeluaran komponen bata yang lebih fleksibel dan lebih sesuai untuk pembinaan. Dalam thesis ini, kajian ke atas penggunaan tanah gambut sebagai bahan binaan ringan dan juga kesan gambut terhadap batu-bata daripada segi kadar ketahanan dan pemindahan haba.

Kajian ini mengkaji ciri-ciri fiziko-mekanikal bata tanah gambut dan pengaruh gambut terhadap komposit bata, serta peranan dalam pelbagai aplikasi pembinaan. Ketahanan bata ini telah diuji melalui 'Spray Test' yang diubah suai yang bertujuaan untuk menguji tahap prestasi spesimen ujian di dalam makmal ujian semburan yang fokus kepada strategi terbaik untuk menangani kemerosotan yang disebabkan oleh hakisan hujan dan angin. Ujian prestasi termo-mekanikal bertujuan untuk memenuhi beberapa jurang sehingga terhasilnya bata tersebut. Kesan penambahan tanah gambut di bata pasir terhadap pengaruh haba telah dikaji melalui perbandingan kekonduksian terma terhadap bata pasir, dan menentukan bagaimana gambut mempengaruhi sifat terma. Teknik adiabatix-box digunakan untuk melaksanakan ujian haba ke atas batu bata dan dijalankan dengan membandingkan data masa-suhu sampel ujian tertentu.

Kajian menunjukkan bahawa kekuatan mampatan, permisahan kekuatan tegangan, kekuatan lenturan, berat unit, halaju denyutan ultrasonik (UPV) telah berkurangan dan kadar penyerapan air telah meningkat dengan peratusan penggantian gambut sebagai agregat dalam sampel. Maksimum 20% daripada (jisim) kandungan gambut memenuhi keperluan piawaian antarabangsa. Hasil eksperimen itu ditentukan dengan penggantian 54% isipadu tanah gambut tidak menunjukkan sebarang kerapuhan, walaupun melebihi beban maksimum dan permukaan yang agak licin ditemui.

Rintangan hakisan bata tanah gambut amat dipengaruhi oleh kandungan tanah gambut dan kualiti percampuran. Peningkatan sebanyak 10% dalam kandungan gambut membawa kepada perubahan negatif mendadak dengan kedalaman hakisan. Ini diikuti dengan pertumbuhan sebanyak 65% dalam kadar hakisan. Spesimen dengan maksimum 20% tanah gambut mempunyai rintangan hakisan yang tinggi tetapi bata dengan 25% tanah gambut memerlukan kemasan permukaan yang baik. Kandungan gambut didapati mempunyai kesan negatif yang luar biasa daripada segi rintangan hakisan

Keputusan ujian thermal menunjukkan secara umumnya penambahan gambut dalam campuran pasir-simen, mengurangkan kekonduksian terma yakni prestasi penebat haba bertambah baik selepas penambahan gambut sebanyak 2.2% hingga 6.2%, bergantung kepada jumlah kandungan gambut ditambah.

Daripada kajian ini, boleh disimpulkan bahawa ciri-ciri kejuruteraan, ketahanlasakan dan prestasi terma bata gambut sangat bergantung kepada kandungan gambut. Penggunaan tanah gambut dan pasir sebagai bahan bata yang effisien mempunyai potensi untuk digunakan di dalam pembinaan dinding sebagai bahan binaan sampingan.

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LIST OF SYMBOLS AND ABBREVIATIONS

C_2S	Dicalcium silicate
CO_2	Carbon-di-oxide
CEB	Compressed Earth Block
CSEB	Compressed stabilised earth block
CSPB	Compressed stabilised peat added bricks
cm	Centimeter
dB	Decibel
Hz	Hertz
ISO	International Standards Organisation
ILO	International Labour Organisation
in	Inche
kg	Kilogram
mm	Millimeter
mg/l	Milligram per liter
MPa	Megapascal
m/s	Meter per second
min	Minute
OPC	Ordinary Portland Cement

PFA	Pulverized fuel ash
RH	Relative humidity
T	Temperature
tcc	thermal conductivity coefficient
UPV	Ultrasonic Pulse Velocity
UTS	University of Technology, Sydney
w/c	Free water to cement ratio
h	hour

CHAPTER 1 : INTRODUCTION

1.1 Background

Worldwide the ever rising demand for the housing sector is pushing for greater requirement of building materials. This expansion is occurring rapidly in the Latin American and Asian countries. In recent decade, the building materials are in high demand due to rising populations. However, in the process of meeting these escalating demands, the environment has been exposed to direct pollution risks (Turgut and Murat Algin, 2007). Despite the above mentioned issue, people nowadays have become more concerned about the environment than ever before. This environmental consciousness induces a progressive effect on the building industry.

In building sector, various categories of brick have significant influence on the energy consumption of the buildings. The most common building brick is the traditionally fired clay brick, in which huge amount of energy is depleted throughout its production (Binici et al., 2005). House construction using available bricks (clay bricks, sand-cement bricks) are too costly for the areas (such as peat reason areas) due to transportation costs, which directly affect the total material cost. The energy used in transporting the building materials is also a factor that contributes to its lower environmental performance. Building materials should be extracted and manufactured locally near the building site to minimize the energy involved in transportation.

Housing construction using earth-based brick or block materials is economical for majority of urban areas due to the energy saving in manufacturing, compared to conventional bricks and transport savings, which directly affect the net cost. Usage of local materials in the building sector can contribute significantly in reducing the energy consumption.

The trend is presently moving on to new schemes and products because the conventional brick can make a major contribution to tracking energy usage, climate change and greenhouse gas emissions (Jiang, 2013; Kim et al., 2013; Paoletti et al., 2007).

Utilization of local raw materials can reduce the cost of bricks by reducing transportation cost, which is an affordable option for the poor communities (Wu et al., 2010). Berge (2009) stated that the energy involved in transportation of building materials plays an important role in its low environmental performance. Therefore, usage of local earth based materials should be prioritized.

Usage of local materials in the building sector can contribute to reduce the energy consumption. Engineers have taken various steps to convert the local materials into useful building and construction materials. Accumulation of raw materials of bricks is a significant problem, and adds to the environmental and cost concerns, especially in area such as peat region. Using peat soil as a building material appears to be a viable solution not only for countering the environment pollution but also for the economical design of buildings. The increase in the popularity of using environmentally friendly, low cost and lightweight construction materials in building industry brings the need for searching for more innovative, flexible and versatile composites. The most important aspects of innovation might be in the development of integrated local construction products.

1.2 Importance of Study

The “Peat” soil is located all over the world, except in the arctic and desert regions. The total surface area of the peat soil is about 30 million hectares, around five to eight percent of the total land in the world. Two-third of the total peat soil is in the Southeast Asia region, which covers approximately 23 million hectares of land (Huat et al., 2005).

According to Wetlands International Malaysia (2009) report, a huge region, around 7.45% of the total land area of Malaysia is covered with peat soil. It is known that peat soil is a highly organic soil, covering around thirty-million hectares of the world, thus housing at those areas can be very cost effective if this soil is used as the raw material for bricks.

The cost of building materials has been often exorbitant, particularly when most of the materials are to be imported. It is preferable to build the houses using locally available materials that may have limited durability, but the cost is within reach of the rural people. Zami and Lee (2011) stated that when construction materials are produced locally using natural resources, semi-skilled labour and few transport needs, such as the contemporary earth construction for low-cost urban housing can be very cost effective. Generally poor stricken communities have better access to natural resources such as the local soil earthen constructions. Besides that, most common building bricks are the traditional fired clay bricks and sand cement bricks, where a huge amount of energy is spent during its production and transportation (Islam et al., 2013).

1.3 Research Problem Statement

The "quality of soil" adversely affects the worth of brick or block, causing shrinkage, cracks, and lower wall strength; compared to that of high-quality fired bricks and sand cement bricks. There are only a few research works in the literature about the potential utilization strategies of peat in the building materials industry (Deboucha and Hashim, 2010; Deboucha et al., 2011).

Both stabilisation and compaction technique are used in line with the compressed stabilised earth blocks, in case of raw materials peat soils and local sand are used with binders. Deboucha and Hashim (2010) conducted a study to discover the effect of using PFA cement and lime mix (pozzolanic waste, a by-product of corn cobs) as an additive in mixer, where the test was carried out on certain number of parameters. The effect of binding materials was presented but it is important to investigate the effect of peat on that bricks. Another concern was that they used a mass percent of binding materials which greatly affected the unit price of a brick.

In order to use structural application, other engineering parameters such as flexural strength, splitting stress and others are required to be investigated as a requirement, as set by the related international standards. This study attempted to investigate the attributes of the composite building material which had different percentages of peat and sand with cement, for different application purposes.

It is known that Malaysia has a tropical climate and experiences two monsoon seasons. The climate is hot and humid all through the year, with an average temperature of 27°C (80.6 °F). In addition, the urban heat of this region affects human activities. The northeast monsoon brings heavy rainfall and the southwest monsoon is comparatively dry. Therefore, the strength of the walls is not a problem, rather the durability due to the erosion of the walls when subjected to continuous rain results in high maintenance demands.

It is essential to investigate wall durability against wind driven rain erosion, which means establishing erosion resistance to reduce maintenance costs in the lifespan of the construction. To ensure thermal comfort and moisture movement, it is necessary to evaluate the thermal performance of the peat added bricks, especially when new materials are being used.

1.4 Objectives of this Study

- To determine the effect of peat content on the physical and mechanical properties of the developed bricks.
- To determine the relative composition of peat for particular requirement in construction of building.
- To investigate the erodibility of peat-added bricks.
- To define the thermal performances of bricks due to peat addition.

1.5 Scope of this Study

This study focuses on determining the effects of peat usage on the physical and mechanical properties of newly developed bricks. In this study, peat soil are gradually increased with a certain limit to produce different mixing properties developed for peat added bricks that can be applied in construction of buildings. The durability of peat added bricks was investigated to assess the effect of wind-driven rain and to predict the erosion resistance in weather conditions, which were simulated based on the laboratory tests on the sample specimens. This study also focused on investigating the effect of peat on the thermal transmittance of the brick and defines the thermal performances as a comparative analysis.

1.6 Structure of this Thesis

This thesis consists of five chapters. Chapter 1 provides an introduction to the entire thesis. It discusses the research background and introduces problems in the traditional bricks. This chapter also summarises the main aims, scopes and objectives of the research.

Chapter 2 introduces the fundamental theoretical concepts of properties and deterioration in compressed earth block and conventional bricks, sufficient information about previous research on engineering properties of compressed peat added bricks.

The research methodology of this thesis include in chapter 3. This chapter provides details of the methods and standards used to implement the testing program of the research. Details of each testing method (Compressive strength, Water absorption, Density, porosity, Splitting strength, Flexural strength, Ultimate pulse velocity, Durability against wind driving rain, Thermal insulation), number and types of tests involved in the research are described in this chapter.

Chapter 4 present the result and discussion of the research. Finding on the engineering properties and comparison of the experimental results and discussed with traditional and previous type of bricks and blocks in this chapter.

Chapter 5 concludes the thesis. It summarises the overall findings of the research.

CHAPTER 2 : LITERATURE REVIEW

2.1 General

Around the world, buildings and related compartments are responsible for at least 40% of the energy usage (González and García, 2006). In many countries, the decrease in per capita energy consumption is measured through minimizing building installation energy and use of environmental-friendly materials. Brick is a fundamental building material for low-cost housing. The traditional fired clay bricks are the widest source of building bricks. Huge volume of energy is used in production of these bricks (Berge, 2012). Ngowi (1997) reported that the temperature of $700^{o}C$–$1000^{o}C$ is required for achieving the required strength and durability for the clay bricks. Thus, the consumption of fuel in the process of brick production causes massive emission of CO_2.

González and García (2006) reported that correct choice of the building materials can reduce CO_2 emission by 30%. Comparing the carbon dioxide emissions of earth blocks and the construction materials used in conventional masonry, González and García (2006) reported that Aerated concrete blocks embodies 375 kg CO_2/tonne, common ceramic brick embodies 200 kg CO_2/tonne, Concrete blocks 143 kg CO_2/tonne, and the earth based bricks embodies 22 kg CO_2/tonne. Earth based building materials had been found to show good environmental performance than others (Morton et al., 2005). Zami and Lee (2011) stated that earth based bricks or blocks are more environment friendly than conversational clay bricks and their production consumes 15 times less energy and causes eight times less pollution than clay bricks.

Transportation energy is involved in the construction industry as building materials are needed to be supplied and this contributes to low environmental performance of building materials. Berge (2012) quantified the energy (Table 2.1) according to the mode of transportation, and stated that the use of locally available materials with earth construction should be prioritized.

Table 2.1: Transportation energy of bricks and blocks (Berge, 2012)

Transport mode	M/ton Km
Railway(electricity)	0.3-0.9
Railway(diesel)	0.6-0.9
Highway (diesel)	0.8-2.2
Plane	33-36

In this regard the natural resources such as, local soil, earthen constructions are cost effective and accessible to poor stricken communities. Meukam et al. (2004) stated that it is preferable to build with locally available material that may have limited durability, but where cost is within the reach of rural people. Therefore, the appropriate choice of building materials can thus contribute decisively in reducing the energy consumption of the construction sector. Hence, brick or block should be energy efficient, environmentally affable and the same time able to carry out all the main high-performance building attributes, as well as requirements of the building standards.

2.2 Earth Based Building Materials

Earth materials are widely used as a building construction material from ages. The history of earth buildings lacks documentation because it has often been considered inferior than stone and wood (Houben and Guillaud, 1994).

According to Dethier (1981), Smith and Austin (1989) about one third to half of the world's population lives in various kinds of earthen dwelling. As stated by Easton (2007) "thirty percent of the world's population or almost 1,500,000,000 people, live in the houses built with unbaked earth. Zami and Lee (2011) and Pacheco and Jalali (2012) state that approximately half population of developing countries live in earth made houses. The rural population of developing countries account for major share in earth made houses. Nevertheless, a minimum twenty percent of sub urban and urban populations live in earth made house.

The earth made houses around the globe can be grouped into different forms. For example, these include cob in the United Kingdom (Hurd and Gourley, 2000), "Rammed earth" around the Mediterranean rim, north India, western China (Jaquin et al., 2008), Compressed Earth Block (CEB) and unfired brick (Sengupta, 2008). As a wall materials the earth based blocks prove advantageous in construction of building; Table 2.2 summarizes some of the advantages.

Table 2.2: Advantages of earth based blocks in building construction

Benefits	Author
Constructions reduce sound insulation and provide better noise control.	Hadjri et al. (2007)
Available materials and easy technique made economically beneficial.	Easton (2007) Lal (1995); Gernot Minke (2007); Morton (2007); Walker et al. (2005); Zami and Lee (2011)
Fully reusable and environmentally sustainable	Adam and Agib (2001); Hadjri et al. (2007); Kolias et al. (2005); Maini (2005); Minke (2006)
Create a new job site and less high skilled labour.	Adam and Agib (2001)
Promotes local culture, heritage, and material.	Frescura (1981)
Most regions earth materials is available in huge quantities and minimize transportation cost.	Adam and Agib (2001); Hadjri et al. (2007); Lal (1995)
Better in fire resistance.	Adam and Agib (2001); Hadjri et al. (2007); Walker et al. (2005)
It improves and balances thermal performance and indoor air humidity temperature.	Hadjri et al. (2007); Lal (1995); Minke (2006); Walker et al. (2005)
It inspires self-help construction.	Minke (2006)
Absorbs pollutants.	Minke (2006)
Required simple tools and easy to work.	Maini (2005), Minke (2006), Hadjri et al. (2007)
Easy to design and build with a high aesthetical value.	Adam and Agib (2001); Hadjri et al. (2007); Walker et al. (2005)
Suitable for strong and safe structure.	Lal (1995); Walker et al. (2005)

Table 2.3 summarizes the disadvantages of un-stabilized Compressed Earth Blocks in a construction of buildings.

Table 2.3: Disadvantages of earth based blocks in building construction

Disadvantages	Authors
Compared to conventional materials it has less resilient.	Hadjri et al. (2007) Adam and Agib (2001), Minke (2006),Walker et al. (2005),Maini (2005) Lal (1995),Blondet and Aguilar (2007)
Perform badly in the time of earthquakes.	Blondet and Aguilar (2007)
Skill labour required for plastering.	Hadjri et al. (2007)
Structural limitations.	Hadjri et al. (2007); Maini (2005)
Require high maintaining cost.	Hadjri et al. (2007)

In un-stabilised compressed earth blocks the soil particles lesser than 0.002 mm swell after absorbing water and shrinking upon drying. This increases the possibility of severe cracking and often leads to difficulties in getting renderings to adhere to the walls, resulting in eventual disintegration. The problems of compressed earth blocks pointed out by different authors in Table 2.3 are solved by incorporating various stabilizers into the compressed earth block.

Many researchers in their published books and works, such as, Maini (2005); Minke (2006), advocate reduction of cracks, increase of compressive strength, enhancement of the binding force and increase in thermal insulation of the compressed earth blocks.

Major saving in energy of about 70%, is the most important benefit of the stabilised earth blocks in comparison with the fired clay bricks. In addition, such bricks or blocks are cheaper than fired clay bricks of around 20% to 40%. A compressed stabilised earth block (CSEB) cost just a fraction when compared to the concrete blocks and timber. The stabilisation of concrete within a compressed earth blocks averaging at 5% (Lal, 1995).

It is known that peat soil is highly organic soil covers around thirty-million hectares of the world, so in those areas housing can be very cost effective if this soil is used as a raw material for manufacturing bricks. In a recent work on the engineering properties of compressed bricks based on stabilised peat, Deboucha and Hashim (2010) had some success with greater specifications of the properties of raw materials.

2.3 Compressed Stablised Bricks with Peat Soil

Peat has high organic content over 75%.It has high magnitude and rates of creep. The percentage of peat varies from place to place due to the variation in the degree of humification and temperature. Humification or decomposition leads to loss of organic substance in form of gas. In addition, the physical and chemical characteristics of peat soil changes due to solubility. It has high water content, lower solid content and low pH values. It is potential to change biologically and chemically with time (Kolias et al., 2005; Maini, 2005). Further, the environment factors also affect the stabilisation process with binder or additives.

To modify the properties of peat and make them useful for the desired applications, stabilisation is a technique that is commonly used. Peat are constructed from graded soils. A hydraulic binder (for example Portland cement) is added to the peat soil and compacted into molds statically or dynamically.

It is known that organic soil can retard or prevent the proper hydration of binders such as cement in binder-soil mixture (Hebib and Farrell, 2003). With high organic content and less solid particles in peat, cement alone as chemical admixtures is insufficient to provide the desirable function for peat stabilisation. Compared to the clay and silt, peat soil has lower content of clay particles that can enter into the pozzolanic reaction (Janz and Johansson, 2002). As such, the interaction between hydrated lime and the soil have less effect in secondary pozzolanic reactions.

$Ca(OH)_2 = Ca^+ + 2(OH)^-$

$Ca^+ + 2(OH)^- + SiO_2$, (soil silica) > $CaO.\ SiO_2 .H_2O$

$Ca^+ + 2(OH)^- + Al_2 O_3$ (soil alumina) > $CaO.\ Al_2 O_3.\ H_2O$

Therefore, no significant strength gain can be achieved from peat stabilisation by cement unless it is added to the soil in a large dosage. Chen and Wang (2006) reported that the weak cementation and hardening of peat-cement admixture is due to the presence of black humic acid in peat soil. Humic acid, fulvic acid, and humin are humic substances, which form the major components of peat organic matter. Humin is the main composition of tightly combined humus, while humic and fulvic acids exist not only in loosely combined humus but also in stable, combined humus.

The quality of cement required for developing desired stabilisation depends on a number of criteria such as, compressive strength, type of soil, environmental dictions and quality control levels. Cement can very easily be wasted if it is not used in the correct manner. Further, proper production management and quality control can significantly reduce cement content. Controlling the moisture content, level of compaction and the curing regime play a major role in getting the most from the added cement.

The presence of the siliceous sand as filler produces no chemical reaction but enhances the strength of stabilised peat by the binder by increasing the number of soil available for the binder. Janz and Johansson (2002) stated that the fillers may enter into secondary pozzolanic reactions as no filler is absolutely inert. For example, inclusions of siliceous sand results in secondary pozzolanic reaction with calcium hydroxide $(OH)_2$ and contribute in improving the strength. However, large size of sand particle with low specific surface; exposes small surface area to the calcium hydroxide for the secondary pozzolanic reaction.

Therefore, investigators neglect the effect of filler on the secondary pozzolanic reaction. Theoretically, by replacing a certain portion of the binder with filler can reduce the cost of stabilised peat added bricks.

Cementation effect in siliceous sand as a granular soil takes place in the form of cementation products that bind the solid particles together at its contact points (spot welding). In this way, the organic particles in peat not only fill up the void spaces in between solid particles but also, they are interlocked by the cementation of the siliceous sand. Thus, according to Kézdi (1979), no continuous matrix is formed, and the fracture type depends on the strength of inter-particle bond or natural strength of the particles.

Deboucha and Hashim (2010) in their experimental work used dry peat soil with the moisture content of peat 13% to 14%. Water and admixture ratio was 24% by the weight of admixture, which was obtained from the plasticity test and used wet mixing method for peat stabilisation. The applied compaction pressure was controlled from 6 to 10 MPa over 3 to 5 minutes after casting the bricks and wet and air cure both were performed for 28 days of curing period. Determination of the engineering properties is a fundamental task in structural analysis and risk-based assessment. As a structural unit, brick need to have certain expected physical and mechanical properties that enable its implementation in an assigned field. Bricks with peat soil have been discussed along with their salient properties in the preceding sections.

2.3.1 Compressive Strength of Bricks and Blocks

The compressive strength of bricks is most important with respect to the other mechanical properties of bricks. It is directly linked to the strength of wall and serves as a common index to the brick characteristics. A significant amount of previous research on brick-wall strength suggests that stronger bricks provide higher brick-wall strength (Hendry, 1990; Lenczer, 1972; Sahlin, 1971).

In light load buildings use low strength bricks such as the sand-cement bricks (Deboucha, 2011). Researchers use a blocks and bricks with wide-range of compressive strength. The conventional compressive strengths of compressed stabilised blocks were found to be not more than 4 MN/m^2 (Adam and Agib, 2001).

The properties of earth brick or block needs to be compared with established industry standards for determining their suitability in the construction sector. Only a few countries have specific standards for the earth related construction materials. Among these countries the minimum criteria set for different standards varies. As an example according to British Standards Institution (1985), common bricks requires a minimum strength of 5 N/mm^2 while Indian Standard (1986) specifies strength of 3.5 N/mm^2 for the same type of bricks (Ngowi, 1997). Table 2.4 (a) and (b) shows the compressive strength of bricks for various standard, and sources.

Table 2.4 (a): Compressive strength of bricks

Standard	Type	(MN/m^2)
British Standards Institution (1985)	Common bricks	5 (min)
Indian Standard (1986)	Common bricks	3.5 (min)
Standards Association of Australia (1984)	Common bricks	5 (min)
Singapore Institute of Standard and Industrial Research (1974)	Common bricks	5.2
Malaysian Standard (1972)	Common bricks	5.2

Table 2.5 (b): Compressive strength of bricks and blocks

Author	Type	
Arnold et al. (2004); Johnston (2010); Raut et al. (2011)	Non-load-bearing	3-5
	load bearing	5-10
Hendry (2001)	Light load building construction	2.8-35
Lunt (1980)	Non-load-bearing	1.2 (min)
Adam and Agib (2001) (summarized some convention value of common bricks.)	Compressed stabilized earth blocks	1-40
	Calcium silicate bricks	10-55
	Fired clay Bricks	5-60
	Light weight concrete blocks	2-20
	Dense concrete blocks	7-50
	Aerated concrete blocks	2-6

The compressive strength of compressed stabilised peat added bricks depends on the properties of soil, amount, type of stabiliser, appropriate mixing of adequate constituents, effectively compaction, and duration of curing period. Meukam et al. (2004) reported that the compressive strength of stabilised laterite-soil bricks varied between 2MPa to 6MPa with 8% cement content. According to Solomon (1994) compressive strength of stabilised laterite-soil bricks ranged between 2MPa to 10MPa with 3% to 10% cement content.

In case of compressed stabilised peat added bricks Deboucha and Hashim (2010) report that, with the increasing cement content of between 20% and 30%, the compressive strength increases by 40%. A 40% increase in compaction pressure resulted in compressive strength that increased from 15% to 32%. They also found that dry compressive strength was higher than the mean compressive strength by 20% to 29%.

The compressive strength of bricks was higher for the Portland pulverized fuel ash cement (PFA) than the ordinary Portland cement (OPC). Compressive strength increases by 52% with increased curing time. Deboucha et al. (2011) found that the compressive strength of compressed stabilised peat added bricks ranges from 7.67 MPa to 2.8 MPa for the cement and lime (20–30%) binding, with cure time of 28 days, w/c ratio of 24% and compaction pressure varying from 10 to 6 MPa.

2.3.2 Bricks and Blocks Density

The bricks density influences the weight of walls and variations in weight have implications on the structural, thermal design and acoustical properties of the wall. Raw materials of brick and manufacturing process govern the density of bricks. Construction industry favors using a low-density bricks (lightweight brick) due to their benefits such as, lower structural dead-load, easy to handle, lower transportation costs, better thermal insulation and increase the percentage of brick production per unit of raw material (Raut et al., 2011; Wu and Sun, 2007).

According to Kadir et al. (2010) lower density bricks can replace conventional bricks except when greater strength is needed. Adam and Agib (2001) present density value of some common masonry wall materials that summarized in Table 2.6.

Table 2.6: Density of common masonry wall materials

Property	Compressed stabilised earth blocks	Lightweight concrete blocks	Dense concrete blocks	Calcium silicate bricks	Aerated concrete blocks	Fired clay Bricks
Density (Kg/m^3)	1700-2200	600-1600	1700-2200	1600-2100	400-950	1400-2400

The density of compressed stabilised peat added bricks is 1300–2100Kg/m^3. Deboucha (2011) reported that this brick is denser than aerated and lightweight concrete blocks and many other concrete masonry products shown in Table 2.5, being about 15% to 20%. They also reported that increasing the OPC or PFA cement, lime and the curing period improved the dry density and that by increasing the cement from 20% to 30% and lime from 0% to 4% the density in the compressed stabilised peat added bricks was increased 5% to 7%.

2.3.3 Water Absorption Properties of Bricks and Blocks

Raw materials used during the production process effects the water absorption property of the bricks (Koroth et al., 1998). In Indian Standard (1992) specifies that the water absorption of brick should be less than 20% of the brick's weight.

Deboucha et al. (2011) in their studies found that the water absorption of peat added bricks decreases from 68% to 14% for increasing cement content from 20% to 30%. They reported a negative relation between total water absorption and the compressive strength. In addition, the total water absorption of peat based bricks decreases with the increasing dry density and increasing curing periods.

2.3.4 **Sound Insulation Properties of Bricks and Blocks**

Sound insulation performance of a wall or a building floor is the ability of wall to transmit sound through the wall from one side to the other side. The capability of the wall to reduce sound that is spreading in the air is express by sound insulation index Rw (dB). Sound insulation properties of a masonry wall can be determined by actual measurement or theoretical calculation. According to Stauskis (1973) the sound insulation index of a wall is calculated by the law of weight or international standard ISO12354–1.The sound insulation index of brickwork is usually accepted as 45dB for a 4.5-inch thick wall and 50dB for a 9-inch thick wall for the frequency range of 200 to 2,000 Hz.

Sound insulation requirement of a building wall is “comparative”, such as requiring a sound insulation as well as a 1/1 stone brick wall or other construction providing at least the same sound insulation. ISO/R 717:1968 was the first international standard designed for sound insulation rating of dwellings (Noise Insulation Standards, 1974). The maximum acceptable unfavorable deviation in this standard at a single 1/3 octave band from the reference curves defined in ISO/R 717 was 8dB.

ISO 717 was revised (International Standard Organization, 1982a, 1982b) and published in the year 1982 but the basic reference curves were the same. Only 8 dB rules were taken out, although deviation-exceeding 8dB had to be reported.

Deboucha (2011) reported that the sound transmission loss through a CSPB wall was 44dB for the frequency range 125 to 4000Hz and a wall thickness of 100mm, at high frequency. For medium and lower frequency, this sound transmission loss was between 24dB to 44dB.

A comparison between the experimental results curve and the ASTM standard curve recommended a maximum deficiency of 30.6dB for 32dB. The maximum difference between each of the points was found to be 7.7dB when 8dB was the ASTM recommendation.

2.3.5 Fire Resistance Properties of Bricks and Blocks

Fire resistance is a property of a building element, part or materials that hold off or delays the passage of extreme temperature, warmth, flames or gases. According to The brick industry association (2008), the fire resistance rating is a time period not exceeding four hours (as fixed in the building code) that a building component, part or arrangement provides the facility to restrict a fire until a given structural function. Table 2.7 shows the rating of fire resistance for different building wall assemblies according to the International Building Code 2006.

Table 2.7: Fire Resistance Ratings for different Partitions and Walls

Materials	Construction	Minimum Finished Thickness, Face-to-Face in. (mm)			
		1hr	2hr	3hr	4hr
Brick of clay or shale[2]	Solid clay brick or shale[1]	2.7 (69)	3.8 (97)	4.9 (124)	6.0 (152)
	Hollow type brick, not filled	2.3 (58)	3.4 (86)	4.3 (109)	5.0 (127)
	Hollow brick unit wall, grouted solid or filled with perlite vermiculite or expanded shale aggregate	3.0 (76)	4.4 (112)	5.5 (140)	6.6 (168)

1. Net cross-section area of cored ≥ 75 % of the gross cross-sectional area of bricks (measured in the same plane).
2. Thickness shown for brick and clay tile are nominal thicknesses unless plastered.

In the American Society for Testing Materials (ASTM) (2002) fire test, the fire resistance period of masonry walls is usually established by the temperature rise on the unexposed side of the wall specimen.

In a compressed stabilised peat-masonry wall study, Deboucha (2011) used a 120 mm thick peat masonry wall and subjected it to temperature of 1200^{o}C. The rate of fire resistance of the peat masonry wall was fund to be more than 5 hours, whereas the recommended value for the same thickness of wall is less than 3 hours.

The brick industry association (2007) report that, the fire resistance limits not only subject to the thickness of the wall but also depends on the dimension of wall.

2.4 Thermal Insulation Properties of Bricks and Blocks

The thermal insulation is property of a material to resist heat transfer when a variation of temperature occurs between inside and outside of the structure. It is representable as the rate at which a brick conducts heat. Thermal conductivity performance of a building material is a vital criterion for saving energy and influences use of a material in the engineering applications. Table 2.8 the thermal conductivity of some common masonry wall from the study of Adam and Agib (2001).

Table 2.8: Thermal Conductivity of common masonry wall materials

Property	Fired clay Bricks	Compressed stabilised earth blocks	Aerated concrete blocks	Dense concrete blocks	Calcium silicate bricks	Lightweight concrete blocks
Thermal Conductivity W/(m.K)	0.70-1.30	0.81-1.04	0.10-0.2	1.00-1.70	1.10-1.60	0.15-0.70

It is necessary to assess the thermal performance of peat added bricks to ensure efficient thermal comfort and moisture movement. It is important to evaluate behavior of new materials. The above properties of the masonry bricks are mainly related to their density or porosity.

Researchers used different type of methods for analyzing the thermal behavior and properties of bricks. Table 2.9 presets common method used by different author in their thermal investigation.

Table 2.9: Experimental method used in different thermal studies

Author/Source	Studies	Experimental method
Yesilata and Turgut (2007)	Thermal insulation property.	The dynamic adiabatic-box technique.
Turgut and Yesilata (2008)	The effect of thermal transmittances.	The dynamic adiabatic-box technique.
Gregory et al. (2008)	The impact of thermal mass on the thermal performance.	Commercial software package AccuRate.
Sutcu and Akkurt (2009)	Thermal conductivity.	Shimadzu TGA -51/51H Software
Coz Díaz et al. (2008)	Numerical analysis of thermal optimisation.	Finite element method.
Oti et al. (2010)	Design values for thermal Conductivity.	Laser-comp FOX 200 thermal conductivity meter equipped with WinTherm32an Software package.
Tavil (2004)	Thermal performance analysis.	Software DOE-2.1E
Binici et al. (2007)	The thermal isolation performance.	Measure the temperature Indoor and outdoor temperatures of the model houses.
Meukam et al. (2004)	Thermal conductivity and the thermal diffusivity	Box and flash method.
Yesilata and Turgut (2007)	Other common thermal performance testing methods.	Transient (dynamic) measurement techniques. Steady-state measurement techniques.

Kadir et al. (2010) estimated the thermal conductivity of a brick specimen using a model. This model was created based on the experimental results that are available in the literature (Arnold, 1969; Ball, 1968; Blanco et al., 2000; Dondi et al., 2004; Glenn et al., 1998). He proposed a relation between thermal conductivity and dry density; and used it for estimating the thermal conductivity of their experimental bricks.

Few standardized techniques commonly used for the accurate thermal testing of the materials are the transient (dynamic) measurement techniques, steady-state measurement techniques. However, these techniques have significant drawbacks in measuring the effective thermal conductivity of the anisotropic materials.

Anisotropy due to crystal structure, material type and form and method of fabrication can cause large variations in property depending on the heat flow direction within the material. The sample geometry displays thermal variations in two perpendicular directions, which must be measured simultaneously. The contact transient techniques, especially the Gustafson Probe or the Hot Disk, have recently been adapted for such a measurement (Lundström et al., 2001).

The anisotropic building materials have relatively low effective thermal conductivity values; thus, sample size tends to be large resulting in longer measurement time (Abdou and Budaiwi, 2005). The location of thermocouples and the quality of contact resistance between the thermocouple and the sample surface are also serious concerns for obtaining accurate measurement. The Virtual Institute for Thermal Metrology (2006) report that, finding solutions to these drawbacks is relatively expensive. However, some efficient techniques exists such as, the dynamical (adiabatic-box) measurement technique developed by Yesilata and Turgut (2007) used for comparative analysis. This is easy to install and is based on comparing time–temperature data of the samples.

2.5 Bricks Durability

The durability and quality of the bricks greatly depend on raw materials and manufacturing parameters, such as increasing cement content and lime, decreasing water absorption (Elert et al., 2003).

Surej et al. (1998) studied the effects of raw material on the brick's absorption property and developed a durability index based on the relationship between porosity and water. It is known that quantity of water absorbed by a brick is a guide to its density and consequently its strength to resist crushing. However, it is not a rational guide to its durability. Adam and Agib (2001) express different state of common wall materials against rain shown in Table 2.10.

Table 2.10: Durability against rain of some common wall materials (Adam and Agib, 2001)

Property	Fired clay Bricks	Compressed Stabilised earth blocks	Lightweigh t concrete blocks	Aerated concrete blocks	Dense concrete blocks	Compressed Stabilised earth blocks
Durability against rain	Excellent to very poor	Good to Very poor	Good to poor	Good to Moderate	Good to poor	Good to Very poor

Durability is the ability to "weather well" in a wall. 'Weather well' describes the performance of bricks without losing their strength, color and texture in a local climatic condition such as rain, frost and wind. The main cause in the durability of earth based wall is the durability of the constituents. This is the cause that the maximum code requirements relate to tests on individual components or wall samples in isolation from their final position in the wall. To analysis the brick durability properties, different author use different methods. Table 2.11 represent some categories that were used by different author in their durability Tests.

Table 2.11: Classification of Durability Tests Relating to Earth based wall Construction

Category	Source	Type
Spray Tests	(Cytryn, 1956)	Accelerated Tests
	(Wolfskill et al., 1980)	Accelerated Tests
	(Venkatarama Reddy and Jagadish, 1987)	Accelerated Tests
	Ola and Mbata (1990)(Ola and Mbata, 1990)	Accelerated Tests
	Bulletin 5 (1987)	Accelerated test. Spraying water horizontally onto samples through a specific nozzle.
	Dad (1985)	Simulation Tests
	Ogunye (1997)	Simulation Tests
	(Heathcote, 2002)	Using commercially nozzle, produces a turbulent spray of individual drops, rather than a stream of water.
Strength Tests	Wet/Dry Strength Ratio (Heathcote, 1995)	Indirect Tests. Use of a ratio between 'dry' and saturated strengths as a means of controlling the durability of earth walls.
	Compressive Strength (Association, 1956)	Indirect Tests
Wire Brush ASTM D559 (1944)	Wire Brush ASTM D559 (ASTM 1944.)	Indirect Tests Methods of Wetting and Drying Test of Compacted Soil-Cement Mixtures
	CraTerre Abrasion Test (Heathcote, 2002)	Modification of ASTM D559 but does not involve any wetting. Indirect Tests used a low strength pendulum sclerometer.
Permeability Criteria and Slake Tests	(Webb et al., 1950)	Indirect Tests
	(Cytryn, 1956)	Indirect Tests accelerated weathering test usually also passed the immersion test
	(New Mexico State Building Code, 1991)	Indirect Tests
	Cartem Soak Test	Indirect Tests
	Sun-Dried Bricks (1992)	Indirect Tests modified version of the slake durability
Surface Hardness Tests	Penetrometer test (Jagadish and Reddy, 1982)	Indirect Tests
Drip Tests	(Yttrup, 1981)	Indirect Tests
	Swinbourne Uni. (1987)	Tests Swinburne Accelerated Erosion Drip Test

The poor durability performance of a brick has been a great limitation to its application and acceptance as a building material. Furthermore, the low performance and comparatively shorter service life of these bricks limit use of these materials.

Resistance against erosion when subjected to driving rain is a crucial factor for the durability of bricks. This often results in high maintenance cost. The impact of raindrops driven by strong wind is the main cause of erosion. In addition, Heavy rainfall is also another major factor of erosion because rain drops hit the wall vertical bearing elements of buildings at an acute angle (Heathcote, 1995)

During a given storm the intensity, raindrop size, impact angle and impact velocity all change with time, making it difficult to simulate under a simple test. Therefore, it is necessary to use "representative" values of these variables. In addition there is evidence to show that this erosion is a function of time, at least in laboratory testing (Ashour and Wu, 2010; Heathcote, 2002).

The life of a building is usually in excess of 50 years. It is obvious that time is the most crucial element in the erosion of earth based building walls. For practical reasons testing must be carried out within a short time frame than the life of a building, such testing is referred as "accelerated" testing. Shortening the time frame needs to be accompanied by an increase in the intensity of degradation factors, and the choice of a suitable test will often lie on the decision as to how much intensification is possible without altering the degradation mechanism.

Tests such as ASTM D559 Wire Brush Test are used for checking the durability of earth-based wall materials. The Wire Brush Test method is used for calculating the least amount of cement required for making the soil-cement bricks. However, the Wire Brush test is not appropriate for characterizing durability problems due to wind driven rain erosions.

The test method Bulletin 5 Spray Test was developed to investigate the wind driven rain erosion. This Spray method and its derivatives, has been used in New Zealand and Australia. This method is catalogued in the building codes for these countries for predicting durability of earth-based bricks.

In particular many methods are developed for durability test of bricks under rain. The traditional spray tests for durability do not adequately model the effects of wind driven rain, especially for the weak materials. In the laboratory test, the spray test Bulletin 5 was adapted by using a commercially nozzle, which produces a turbulent spray of individual drops, rather than a stream of water. The spray test, modified by Kevan Heathcote and Moor (2003), which had a spray testing rig built at UTS according to the bulletin 5 specifications provide a scientific basis for acceptance testing in-situ durability of earth based wall materials for specific climatic area.

It would be highly desirable to directly measure the effect rainfall variables have on the erosion of specimens. This is impractical however, as storms comprise of raindrops approaching at different angles and impact velocities, depending on wind strength and rainfall intensity. The best that can be done is to keep as many of the secondary variables as possible constant, and to examine the effect which primary variables have on erosion, and this can only be done in a laboratory. In this investigation, one of the main deterioration mechanisms was wind driven rain erosion. The bricks durability is consequently evaluated on the basis of their resistance to the erosion.

2.6 Summary

As reviewed in the earlier section it was observed that:

- Housing construction is costly when materials are imported. The transport cost directly affect the total costs. It is preferable to build with locally available materials that may have limited durability, but where cost is within the reach of people. Compressed stabilised earth bricks include, uniform building component sizes, available materials and making a much more affordable option for poor communities by reducing amount of imported materials and fuel.
- Simplicity of producing compressed stabilised earth bricks is an advantage. Therefore, individuals and communities as a whole can easily participate to build their own affordable homes due to the flexibility and simplicity in technology incorporated to compress stabilised earth bricks. Such techniques are affordable adaptable and knowledge between different stakeholders can be easily transferred .
- Previous research works have investigated the effect of binding materials but it is also important to investigate the effect of peat on bricks. In this regards other engineering parameters are required to be investigated to meet the international standards.
- High maintenance cost is main the problem in comparison to the strength of wall. Maintenance is involved for longer durability to counter the erosion of the walls due rain. In addition, it is also necessary to evaluate the thermal performance of the peat-added bricks to ensure thermal comfort and moisture movement.

CHAPTER 3 : RESEARCH METHODOLOGY

3.1 General

The present study focuses to evaluate effects of peat addition on the peat added bricks. In addition, this study investigates performance of peat added bricks to withstand extreme weather conditions. Further, this work compared the effect of thermal transmittance between the ordinary bricks and peat added bricks. The production of peat, siliceous sand and cement solid bricks to the role of various types of constructional applications were also been investigated. In this regards, an experimental study was performed for investigating the physical and mechanical behaviour of peat added bricks.

Literature review was conducted for the traditional bricks, blocks, peat stabilisation process and mix design of compressed peat added bricks to achieve logical thinking level and provide an intellectual context for the research progress.

Laboratory experimentation and testing was conducted to provide the engineering properties of peat added bricks, which was mix dry peat and mixed with binding materials, sand and water using the electric mixer and compressed inside steel moulds under pressure.

After one day curing period, mould was removed and specimen was transferred to moist cured room for various curing time. Two size of sample were used to determine the engineering properties. This experiment investigated considered different peat content in the peat added bricks.

The durability of the specimens was evaluated through a laboratory spray testing. This test involves spraying each specimen with water that are emitted at a known pressure for a given time period. To analyse the nature of erosion with time, readings were taken at an interval 15 minutes where the erosion depth could be easily established.

The dynamic adiabatic-box technique was used to investigate thermal behaviour of peat added bricks. The aim of this test was to investigate effect of peat addition on thermal transmittance of the brick. Therefore, the transient thermal behaviours of three peat-brick specimens (R-20, R-15, and R-10) were compared with the control sample (shown as R-0).

3.2 Laboratory Testing

Mechanical characterization is a fundamental task in structural analysis and risk-based assessment. As a structural unit, brick represents certain expected physical and mechanical properties that enable its implementation in an assigned field, such as in building or as a facing among others. The lab program involved basic engineering properties of peat soil (Specific gravity, Sieve analysis, Atterberg limit, and pH) and physical and mechanical properties of peat added brick (Compressive Strength, Flexural Strength, Splitting Strength, Ultrasonic Pulse Velocity (UPV), Unit Weight values and Water Absorption values). The chapter describes the method employ for erosion resistance and thermal behaviour of peat added bricks. All the research testing were performed through laboratory testing. Figure 3.1 presents flow of this research study.

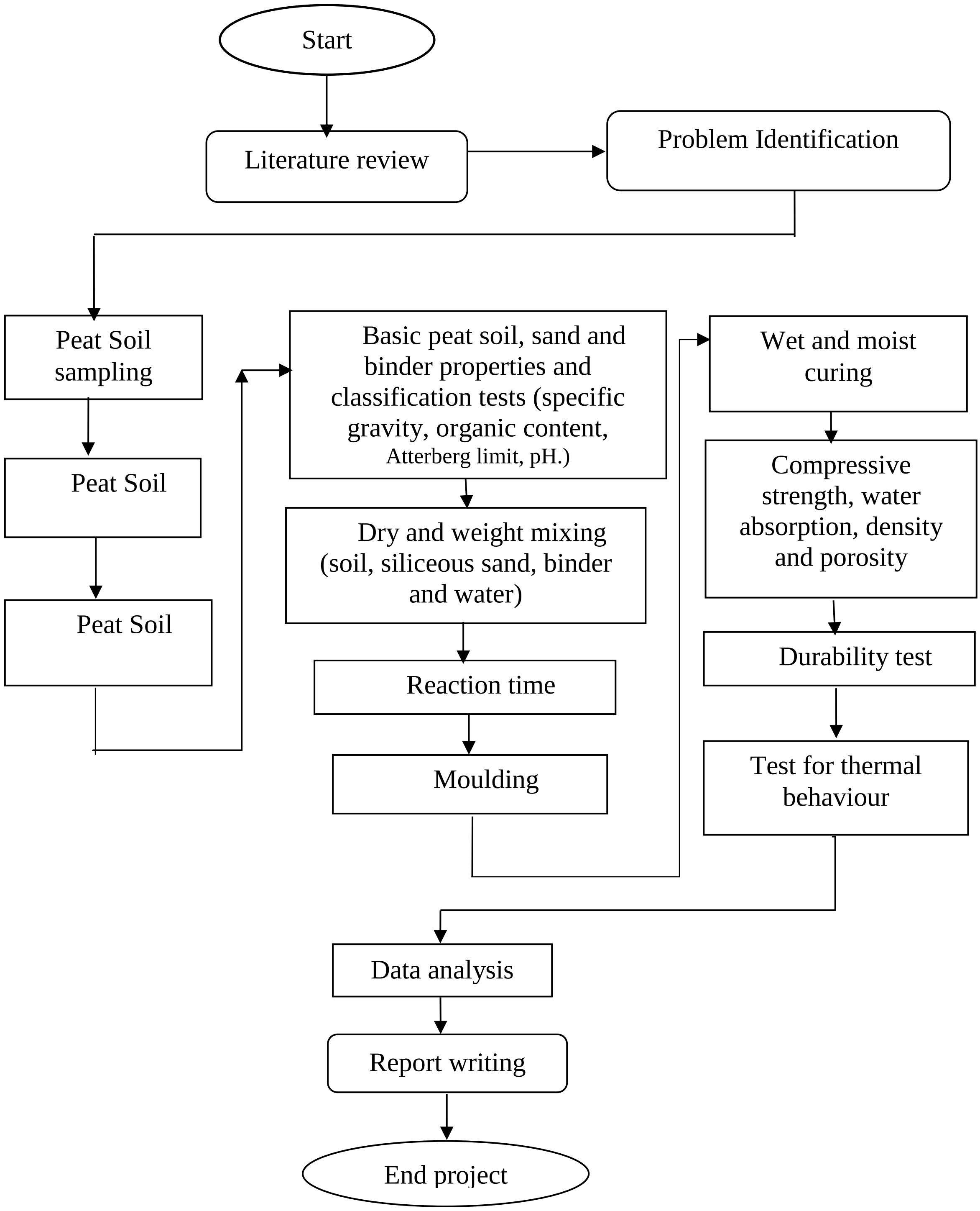

Figure 3.1: Flowchart summarizing the research

3.3 Constituents of Peat Added Brick

The innovative brick manufacturing concept like peat added bricks has been studied to find out eco-friendly and cost-effective building brick in the construction sector. Such composite brick uses locally available materials to meet the target. Materials used in this progression have been discussed along with their salient properties in the preceding sections.

3.3.1 Materials

Several raw materials have been used to manufacture the peat added brick. Brief descriptions of the materials are stated as below.

- Peat soil were collected from the site, and excavated to a depth of 0.5 m below the ground level. It was dry enough to sieve and remove the coarse materials such as roots, stone, large fibers and particles ranging in size from 2 mm to 0.075 mm.
- The siliceous sand materials are collected from the local market in Malaysia, the maximum being 2mm in size was used to increase solid matrix to the peat.
- The Ordinary Portland cement (OPC) are used as a binding materials. The hardness, sulfate content and pH value of the supplied water are 3.7, 5.6 mg/l and 6.2 respectively.

3.3.2 Characteristics of Peat Soil

Peat is a plant-rotten soil whose rate of accumulation is faster than the rate of decay. It has high magnitude and rates of creep. The percentage of peat varies in terms of place due to the factors; degree of humification and temperature.

Humification or decomposition involves the loss of organic matter either in gas or in solution which causes disappearance of the physical structure and change in chemical state.

Its high organic and water content shows different mechanical properties and its consolidation settlements are time consuming even moderate load is to be subjected (Deboucha et al., 2008; Jarret, 1995). Low bearing capacity, strength and high compressibility make it unsuitable for supporting base in its original state and it involves the chance of excessive settlement and ground failure (Edil, 2003; Hebib and Farrell, 2003). The physical and chemical components of peat changes with time biologically and chemically. The soil could be classified as H_4 according to Von Post degree of himification because upon squeezing, releases very muddy dark water, passed between the fingers but the plant remains are slightly pasty and the plant structure was hardly indentifical. The properties of used peat soils in this study are presented in the Table 3.1.

Table 3.1: Properties of peat soil used in this study

Properties	Value
Bulk density (γ_b)	1.1 Mg/ m^3
Dry density (γ_d)	0.194 Mg/ m^3
Fiber content	80%
Specific gravity (*G*s)	1.48
Void ratio (*e*)	7.5
Classification /Von Post	H_4
Loss on Ignition	98.5 %
Liquid limit	165.2%
Plastic limit	125.10%
Plasticity Index	40.1%
Linear Shrinkage	5.6%
pH	4.6

Huat et al. (2005) reported that the liquid limit of peat soil is in the large range up to 500%. The higher value of bulk density is present in Table 3.1 due to subsiding, shrinkage, or mineralization. High water content, lower solid content, low pH values and at the same time environment are also the factors affecting peat stabilisation process (Martinez and Tabbaa, 2009; Huat, 2002). Many researchers such as Kolay et al. (2011); Kumpiene et al. (2007); Moayedi et al. (2014); Wong et al. (2008) studied different facts of peat stabilisation. Wong et al. (2013) reported the strength of stabilised peat mainly depend on the amount of binder, silica sand, initial pressure and duration of curing period.

3.3.3 **Role of Cement**

Cement is usually used in construction industry, as it has power to stabilise clay and sandy soil. Adam and Agib (2001) stated that cement has power to increase the plasticity index and decrease the liquid limit of the sediment soils, thereby increases the workability of the soil.

Hydration of cement starts when water is added and this reaction creates a cementitous gel which is independent of the soil. Cementation process of the earth block embeds the soil particles within a matrix of cementitous gel. In simple terms cement acts as a coating layer around the soil particles (Adam and Agib, 2001).

The main purpose of cementation is to create soil water-resistance and to increase the compressive strength of structure. Ithnin (2008) said that theoretically, cement can stabilise all the soil. However, in experiment Adam and Agib (2001) showed that increase of silt and clay content in the soil requires more cement. To explain this reason Hall (2009) confirmed this theory, “if soil content contains finer particles than cement particles, then it cannot be coated by cement”. So more cement is required to ensure all particles are satisfactorily coated. This makes it uneconomical because it requires a substantial amount of cement than usual.

The particle size of sand and peat greatly influence the percentage of cement content. The grading of used peat soil and siliceous sand are presented in Figure 3.2.

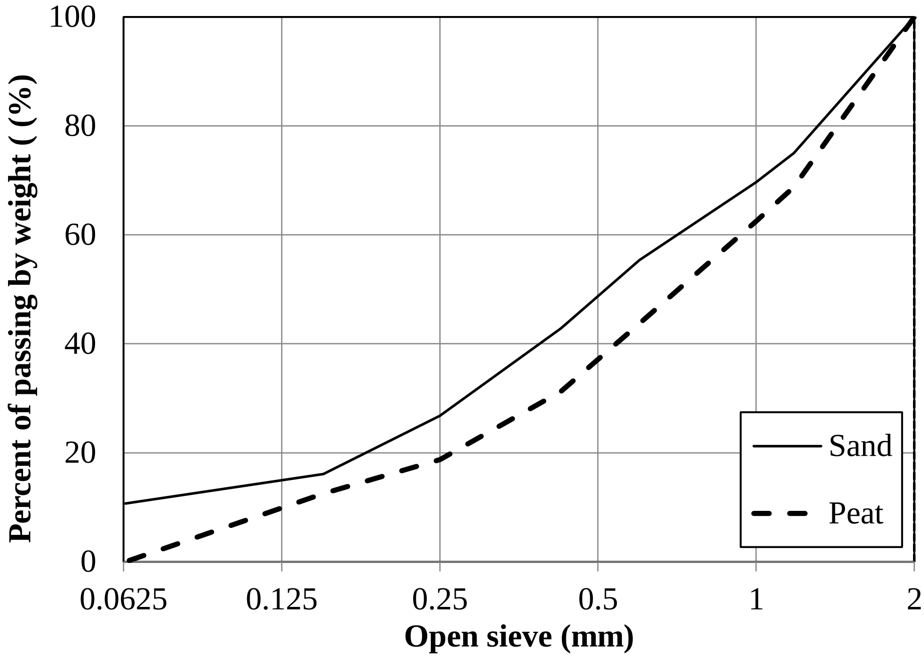

Figure 3.2: Grading curves of peat and sand

Cement and lime used in bricks act as a source of reactive silica and alumina. They are responsible for the development of strength. Consolidation of materials is influenced by the pozzolanic reaction in the binder and pozzolanic reactions depend on water content. Meukam et al. (2004) indicated in their investigation that the compressive strength of stabilised laterite soil bricks varied between 2MPa to 6MPa with 8% cement content. According to Solomon (1994) compressive strength of stabilised laterite soil bricks ranged between 2MPa to 10MPa with 3% to 10% cement content.

In peat based bricks, Deboucha and Hashim (2010) stated that, with increasing cement content of 20% to 30%, the compressive strength increases by 40% and brick strength range 2.8 to 7.6 MPa. They also reported that increasing the cement improved the dry density, decrease water absorption, porosity. It was found that the bricks density increased from 5% to 7%; and water absorption decrease 68% to 14%.

In brick cement is the most costly raw materials. The percentage of cement effect many factors such as unit price of brick, environment and total cost of constructing a house. In this study considered a 20% cement content and investigated relative composition of bricks, having different levels of peat as a replacement for sand aggregate, for the different application's purpose and investigate the effect of peat addition.

3.3.4 **Effect of Sand Grain Size**

The grading of siliceous sand is very important to build strong stabilised peat, because the void spaces within the stabilised soil is reduced to a minimum when it is well packed with coarse grained sand filling the interstices with fine grained sand (Wong, 2010). The inclusion of the siliceous sand as filler produces no chemical reaction (Deboucha, 2011) but enhances the strength of the stabilised peat by the binder due to increasing the number of soil particles available for the binder. Table 3.2 presents the chemical composition of cement, sand and peat that was used in this study.

Table 3.2: Chemical composition of Cement, Sand and Peat

Component	Cement (%)	Sand (%)	Peat (%)
Silica (SiO_2)	21.60	70.30	3.1500
Alumina ($Al2O_3$)	6.280	19.20	0.8500
Iron oxide (Fe_2O_3)	3.700	0.033	0.6900
Phosphorus pent oxide (P_2O_5)	0.090	0.731	0.0310
Calcium oxide (CaO)	66.23	2.15	0.3000
Magnesium oxide (MgO)	0.890	0.390	0.2300
Sulphur trioxide (SO_3)	0.020	0.160	0.5300
Potassium oxide (K_2O)	0.63	3.750	0.0110
Sodium oxide (Na_2O)	-	-	0.0300
Titanium dioxide (TiO_2)	0.220	0.045	0.0069
Chlorine (Cl)	-	-	0.0710
Carbon dioxide (CO_2)	-	-	93.000
Manganese(II) oxide M_nO	0.080	2.125	-
Zinc oxide Z_nO	0.010	0.041	0.003

Cementation products bind the solid particles together as its contact point (spot welding). The organic particles in peat not only fill up the void spaces in between the solid particles but also, get interlocked due to cementation of the siliceous sand. Thus, according to Kézdi (1979) no continuous matrix is formed, and the fracture type depends on the inter-particle bond or the natural strength of the particles themselves is stronger.

Ismail et al. (2002) reported the effects of sand inclusion in the cementation of the porous materials using calcite. They also mention that the excellent strength performance of the rounded sand particles is due to their round shape. The sand particle is almost spherical in shape and uniform, and the structure of each particle is strong with practically no inner voids. They further stated that the spherical particles of sand allows the sand to have more contact points with the surrounding grains and this contributes to the cemented matrix to have many welded contact points.

3.4 Test Samples

Six types of combinations were prepared for the laboratory test. In Table 3.3, the properties of fresh mixes are presented. The percentages of replacement between peat and siliceous sand are taken as weight replacements such as, five percent replacement of peat soil means that five percent of the corresponding siliceous sand weight was exchanged by the peat and corresponding specimen be present as R-5. The peat soil is of less unit weight that means higher volume contents. Table 3.3 also shows the volumetric replacement corresponding total volume.

Table 3.3: Mixing composition of brick sample

Mix design	Cement (%)	Sand (%)	Peat (%)	Optimum moisture content (%)	Percentage of peat volume (%)
Control mix	20	80	0	18	0%
R-05	20	75	5	19	13%
R-10	20	70	10	20	28%
R-15	20	65	15	21	37%
R-20	20	60	20	22	44%
R-25	20	55	25	22	54%

Percentages of water in the combinations depended on the percentage of moisture content of each mixture. The quantity of cement was taken 20% of the total weight of each combination.

The peat, sand and cement contents were placed in the electric mixer machine and mixed for two minutes to obtain the uniform mixing. It was seen that peat soil evenly mixed within the mixes. Then water was added slowly into the mixer machine while the mixer rotated. An extra three minutes of mixing was performed. The mixtures were then fed into moulds. The amount of water content was increased with the increasing peat content.

The brick mould was fully filled with this fresh mixes having the proportions indicated in Table 3.3. Without any delay the mix was pressed into the mould under pressure with a hydraulic jack machine. It was connected with a load cell and data-logger to control the pressure. After 5 minutes under pressure 7 MPa, the moulded brick samples were air cured for 24 hour. Later on the mould was removed.

In order to control the setting or hardening of cement and stop disintegrating, the brick sample was cured in humid environments for getting best results. The brick samples were cured for duration of 7, 14 and 28 days.

Following this procedure totally 158 numbers of samples are prepared. The dimension and quantity of samples prepared for the corresponding experimental test are described in Table 3.4.

Table 3.4: The dimension and the quantity of samples used in this study

Mix no.	Water absorption, Unit weight,Compressive strength (7days, 14days, and 28days).	Splitting strength, Flexural strength and UPV.	Durability Test	Thermal Test
Control mix	3×4	3×3	-	3
R-05	3×4	3×3	-	-
R-10	3×4	3×3	5	3
R-15	3×4	3×3	5	3
R-20	3×4	3×3	5	3
R-25	3×4	3×3	5	-
Total	72	54	20	12
Dimensions (mm)	70×70×70	100×70×220	100×70×220	100×70×220

3.5 Experimental Procedure

A series of tests considering various samples were undertaken according to British Standards Institution (1985) and American Society for Testing Materials (ASTM) C 67-03; C 67-02, to define the corresponding compressive strength, splitting strength, flexural strength, unit weight values and water absorption values. The information regarding these experimental procedures is presented here.

3.5.1 Water Absorption and Unit Weight

After finishing the curing period, the water absorption test was performed. The test samples were positioned into a ventilated oven at a constant temperature of 65^{o}C. They were drawn out over a period of 48 hour and weight was measured after it cooled to room temperature. Afterward, samples were placed in the water tank and fully submersed for 48 hour.

The samples were taken out and kept for a while to drain out the surface water. At that juncture, using a damp cloth the apparent saturated surface was removed and weighted immediately. This is the saturated weight of the sample. The water absorption was determined from this saturated weight and the dry weights. It is an important parameter for bricks. It indicates the permeability of bricks (Ahmari and Zhang, 2012).

The unit weight was calculated from their mass and overall volume of the sample. Brick unit weight decreases over curing time. Unit weight of moulded bricks is very low comparatively to other building materials due to the very high porosity (Vinai et al., 2013).

3.5.2 **Compressive Strength Test**

The auto-controlled compression test machine was used to determine the compressive strengths of the sample. Both the applied load value together with compressive strength were obtained from the auto-compression test machine.

3.5.3 **Flexural Strength and UPV Tests**

The flexural strength of the brick sample was determined through the three-point bending test. The width of sample is 100 mm, depth 70 mm and the supporting span is 160 mm. The UPV value was taken from the brick sample following British Standards Institution (1997). This UPV value of a material is a function of its density and elastic modulus. This value can be used for evaluating the uniformity and quality of materials. To determine the direct UPV values, following methods were employed.

A pulse transmitter was located on one side and a receiver on direct opposite side of the brick sample. When the ultrasonic pulse transmitted through the brick length of 220 mm, travel time was conveyed using a timing device.

Then UPV of the sample was calculated using the relation: Pulse velocity = (Path length/ transit time), where path length is the brick length.

3.5.4 **Splitting Strength Test**

The splitting strength of the peat added brick was done on the brick samples with a size of 100 mm X 70 mm X 220 mm. The compressive line load was applied through two 220 mm parallel steel edges. One was placed on the bottom of the sample and another at top. The splitting strength of brick was determined from the applied line load at which the tensile cracks form parallel to the brick edges.

3.6 Durability Test

After analyzing both physical and mechanical properties of peat based bricks from the laboratory test, the author identified the erosion resistance of peat based bricks. The purpose of this test was that where the existing bricks are not ideal for use in the production of compressed bricks. Materials used in this investigation are discussed along with their salient properties in the preceding sections.

3.6.1 **Materials and Sample Preparation**

The raw materials used in manufacturing of the peat added bricks were discuses previously. Three combinations were prepared for this test. In Table 3.5, the combinations of fresh mixes are presented.

Table 3.5: Mixing composition of brick sample

Mix design	Cement (%)	Sand (%)	Peat soil (%)
R-15	20	65	15
R-20	20	60	20
R-25	20	55	25

In selected accelerated erosion tests, an attempt was made to model the service degradation process. Therefore, the intensity of the degradation factors was increased to compensate for reduced time frame. Release of the kinetic energy associated with raindrops impacting on the surface is the primary cause for the removal of material from the surface of vertical elements (e.g. bearing walls). This scheme is similar to that assumed in for determining the sediment run off during a storm.

The experimental methods consisted of spraying the surface of a test specimen for a time period. The approach adopted in this study is based on the method introduced by Heathcote (2002), which assumes and take proper test consideration for minimum 50 years of service life for the structures. Bearing in mind that a building life span is usually in excess of 50 years, it is obvious that time is the most crucial parameter in the evaluation of the erosion in building walls. However, due to practical reasons laboratory tests needs to carry out investigation within a much shorter time frame than the life of a building. Such testing is referred to as “accelerated” testing. Shortening the time frame is accompanied by an increase in the intensity of the degradation factors. Therefore, the choice of suitable test often depends on the decision as to how much intensification is possible without altering the degradation mechanism.

The Spray test mechanism is established in different countries individually. For example, in Australia, the National Building Technology Centre developed a spray test named Accelerated Erosion Test (Heathcote, 2002), mainly for testing adobe bricks, even though it is practical to compressed earth based bricks and rammed earth samples. In this experiment, modified spray test was incorporated (Heathcote, 2002; Heathcote and Moor, 2003).

A simple testing device was installed in laboratory, as indicated in the schematic diagram in Figure 3.3, to simulate the erosion process by wind driving raindrops.

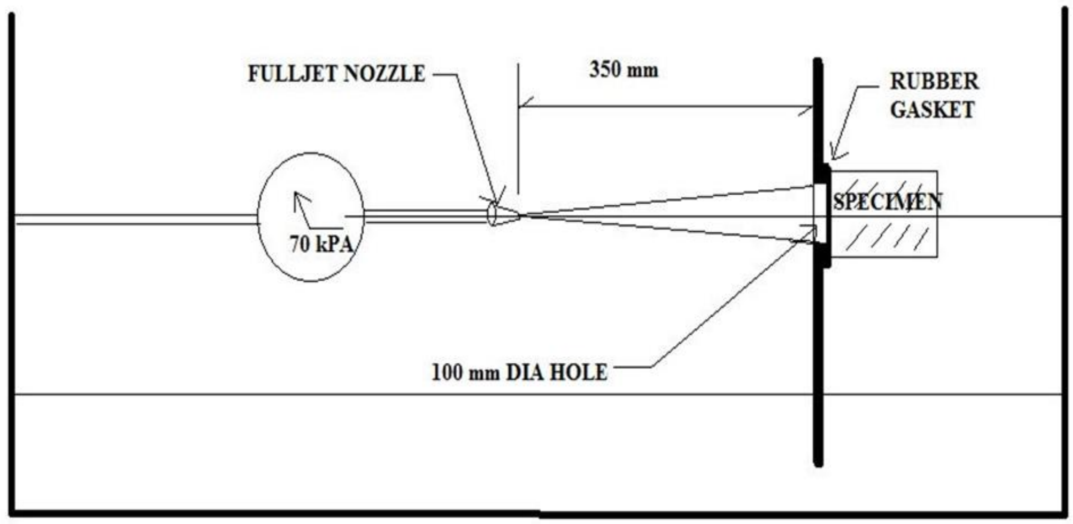

Figure 3.3: Schematic view of the brick erosion test

In the experimental arrangement, the test samples were positioned with their outer surfaces exposed to the spray. The sprayed water impacted the samples through a diameter hole of about 100 mm. A Full jet nozzle was placed at a distance 350 mm from the existing surface of the sample. Water pressure was controlled at 70 kPa using a valve and a data logger. The runoff water was filtered before recycling. Water drops were dripped out through a nozzle at a continuous level of around 9.5mm^3/ min.

The surface winds over Malaysia are generally mild, with the mean speed of about 3.5 m/s and average annual rainfall not less than 1787 mm (Malaysian Meteorological Department, 2014). The specimen service life was assumed to be 50 years old and the spraying time was calculated 90 min to count the erosion depth of specimens in the laboratory. To analyze the relation of erosion nature with time, readings were taken at every 15 minutes, and the erosion depth could be easily established per minute at any period of spray time or wholly.

Figure 3.4: Brick erosion test setup

3.7 Thermal Performance Test

The dynamic adiabatic-box technique was used to perform the thermal tests for the bricks samples, as proposed by Yesilata and Turgut (2007). The diagram of the testing device is presented in Figure 3.5. The adiabatic-box was the key part of this device, and to decrease heat losses from the box, the exterior and lowermost box walls were greatly insulated by 15 cm thick walls from all sides. The test sample with much higher thermal conductivity and thinner in size formed the upper wall of the adiabatic-box to provide one-dimensional axial heat flow.

The appearance and geometrical dimensions of adiabatic-box are presented in Figure 3.6. The adiabatic-box included a temperature-controlled heater. The heater was set adjacent to the bottom of the box wall for providing heat at 10 cm depth of water up to a definite temperature. The water assisted to obtain more uniform temperature distribution in horizontal direction during heating and transient experiments.

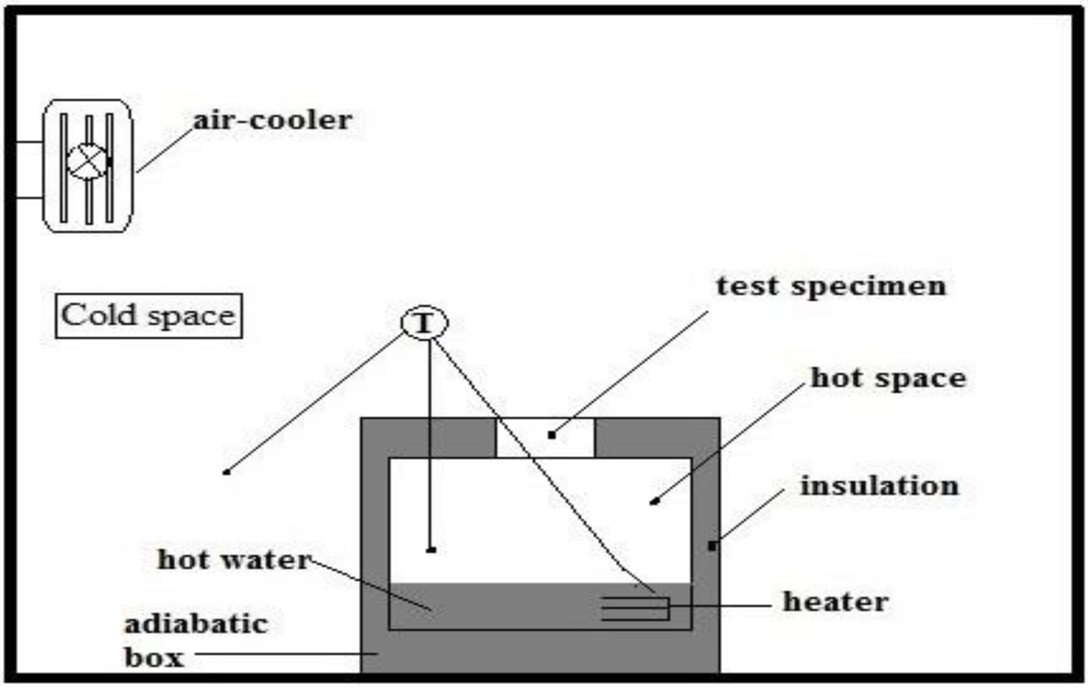

Figure 3.5: Diagram of dynamic adiabatic-box

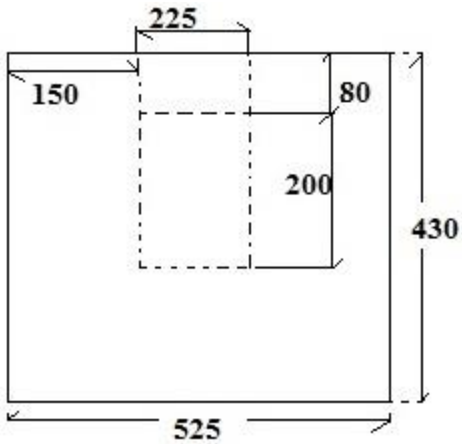

Figure 3.6: Dimensions of the adiabatic-box apparatus (in mm)

The operating temperatures were designated between 35°C and 62.2°C to prevent water evaporation. The adiabatic-box was positioned in a cold chamber, and the chamber had controllable temperatures, humidity and air flow conditions.

The adjacent air temperature and relative humidity were measured using temperature and relative humidity devices at different places in the chamber. An outline of this experiment is a briefed below, whereas a detailed description is described elsewhere (Yesilata and Turgut, 2007).

A highly sensitive thermometer was used to detect the water temperature, connected with an internal data logger and its sensor was contact with water. The sample was tightly fitted on the box and when water reached to a preferred temperature, the heater would be twisted off and transient data recording would starts at this point in time (t = 0). Water cooling rate was considered a quantity of sample thermal transmittance, since maximum portion of the heat was passed through the sample.

The main objective of thermal tests describe here was to investigate the effect of peat adding on the thermal transmittance of the tested brick sample. The transient thermal behaviours of the peat added brick samples (R-10, R-15 and R-20) were thus compared with the sand-cement control mix sample (R-0).

The comparative analysis for the brick sample was started in cooling period. The cooling rate of water, which was directly related with the thermal transmittance of the specimen, was disputable since major heat loss passed through from the specimen surface. Some heat losses at insignificant level could be possible from the other surfaces of the box; however, this should not affect comparison since all specimens were subjected to the same internal and external conditions.

The instant cold room temperature value was found by averaging the instant temperatures taken at three different places in the cold room. The cooling time was considered long enough to make fair comparison between the tested samples.

CHAPTER 4 : RESULTS AND DISCUSSION

4.1 General

In this study, peat was investigated in tandem with the production of light weight bricks. Peat, siliceous sand and cement mixtures were autoclaved under different test conditions to produce brick samples.

Brick is one of the most popular building materials in many countries due to its useful properties. Conventional brick types are commonly burnt clay bricks or cement sand blocks (Jayasinghe and Mallawaarachchi, 2009). The alternative types of bricks have comparable performance and appearance, such as peat added bricks. Hence, there is a necessity to ensure adequate performance of peat added bricks in term of strength, water absorption, porosity, flexural strength, splitting strength, ultrasonic pulse velocity. Thus in this study, a laboratory test was conducted for determining the effect of peat addition on the engineering properties of bricks.

Earth based compressed bricks have limited durability compared to conventional building materials (Hadjri et al., 2007; Maini, 2005). The energy efficient building materials and techniques such as compressed bricks remain problematic as they require frequent repairs (Guettala et al., 2006). This problem is more common in hot and humid climatic conditions. The poor durability performance of the brick has been a great limitation to its application and acceptance as a building material. Furthermore, the low performance and comparatively less service life of the building materials moderate the feasible practice of the material. For effective prediction of the service life of peat added brick, it is important to take an accelerated durability test, which is a reliable predictor of in-service performance. A fundamental factor for the durability of bricks is the stability against erosion when subjected to rain, and which often results in high maintenance demands.

In this study, the durability of this bricks was tested through modified Spray Test. This study aimed to examine the performance of the test specimens in a laboratory spray testing to focus on the competent strategies to counter deterioration due to wind-driven rain erosion.

One of the essential requirements of a building material is that it should permit the heat to pass as little as possible. In tropical climatic region such as Malaysia, heat carriage is an important consideration that must be factored into the design of suitable and affordable housing. In hot climates areas, sometimes the passage of heat is maintained by increasing the wall thickness. A study on the thermal performance of the newly building materials is necessary in order to relate the brick strength qualities to the corresponding thermal comfort.

In this study, the test results from the experiment on peat added bricks were analyzed with a view identifying general trends, as well as comparing the performance of counterpart ordinary sand brick and peat added bricks. The results were then used to validate or query theoretical assumption as presented in chapter 2 and 3 of this thesis.

4.2 The Engineering Properties of Peat Added Bricks

The physico-mechanical tests were performed to investigate the effect of peat addition and whether the design samples content the requirements as a construction material matching with the relevant standards. Figure 4.1 illustrates whole picture about the physico-mechanical properties of sample obtained from the test series. The dimensionless ratios of parameters are plotted as a function of peat percentage. Dimensionless values were obtained by selecting maximum value of corresponding parameter as a scaling parameter; that is:

$$\overline{Y} = \frac{y}{Y_{max}} \qquad 1$$

In Eq. (1), for any parameter (i.e. unit weight), Y is dimensionless value, y is point value of each sample, and Y_{max} is the maximum value in the test series for the same parameter.

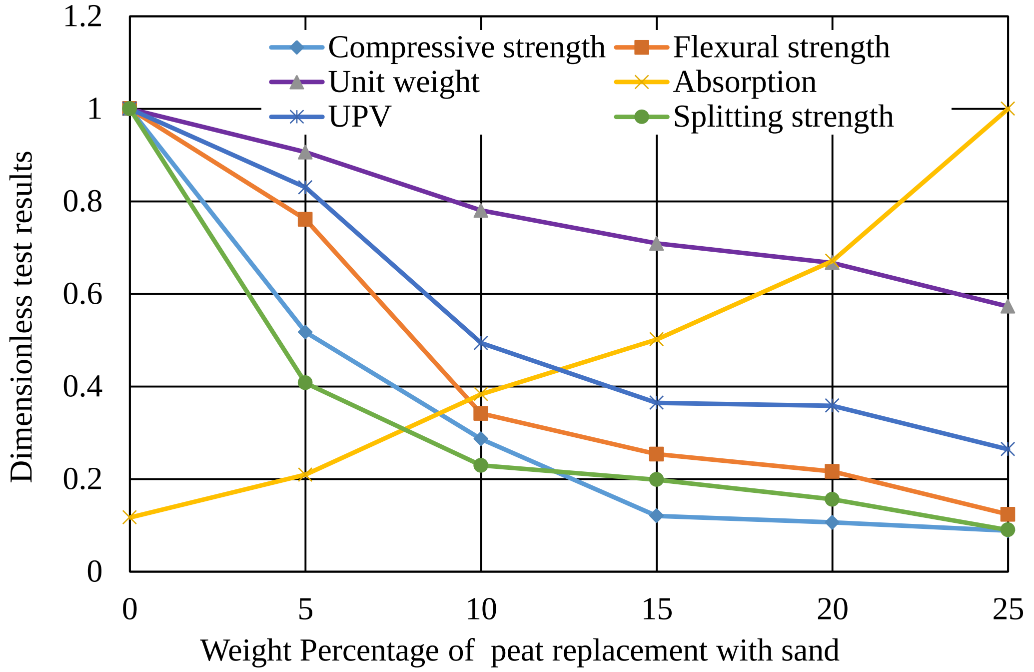

Figure 4.1: Dimensionless values for physico-mechanical properties

Figure 4.1 illustrates the maximum value of all parameters in this test series. The only exception of water absorption properties, correspond to that of the control mix specimen since unity values were found for 0% peat content. Both the percentage of water absorption (% mass) and porosity of sample monotonically increase with increasing peat. On the other hand, the unit weight and UPV values decrease with increasing peat percentage. It was observed that increase in porosity results in a decrease in UPV values subsequently decreases the unit weight and cause with an increase in water absorption.

Obtained test value represents qualitatively expected trend for lightweight building materials. In Figure 4.1 these trends illustrate more clearly where water absorption (%

mass), UPV and unit weight are considered as dimensionless values. It is seen that the dimensionless unit value of UPV and unit weight relate to control mix sample.

On the other hand, in case of water absorption it relates to R-25 sample. This is for the reason that the maximum water absorption value was obtained for the sample R-25 in the test series and thereby it was taken as scaling value.

4.3 Total Water Absorption

Brick and blocks are known to absorb water through the capillarity action (Keddie and Cleghorn, 1980). The amount of water absorbed by a brick is a vital property for various purposes such as quality, comparison purpose, classification of bricks, and a useful measure of bulk quality and total volume of voids.

The total water capacity of a block or brick can usually be measured by determining the amount of water it can take in (Austen and Miles 1987). The bricks' pre-existing moisture are greatly influenced to determine the water absorption capacity. Therefore brick sample is usually dried before testing to keep the mass constant (The British Standards Institution, 1985). There are several procedures that can be applied to determine the bricks' water absorption properties. For this study, the procedure that was used for the determining the total water absorption was through cold immersion in water 48 hours after going through ventilated oven drying.

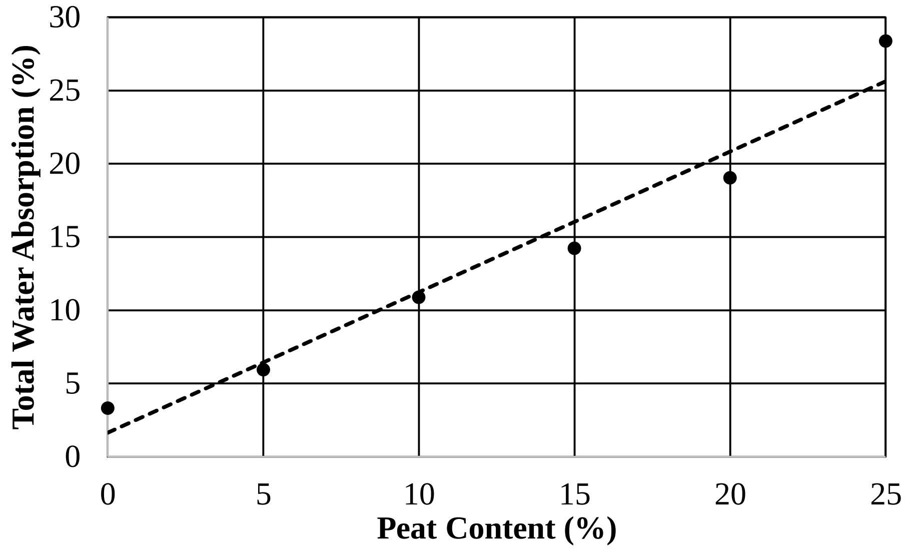

Figure 4.2: Relationship between peat content and the total water absorption

The test result shown in Figure 4.2 illustrate that the presence of peat highly influenced the water absorption properties of bricks. There is a linear relationship between water absorption and peat content; the coefficient of relationship, which shows positive values (0.96) of coefficient for the samples studied. It is known that peat has high water content, possessing liquid limit above 150% (Huat et al., 2005). The 20% peat content is found to gain 78% increase in water absorption. However it is clear that the water absorption below 20% with increase peat up to 20% is comparatively well with other similar materials and recommended maximum value for bricks.

Ajam et al. (2009) report that, the water absorption values of PG fired bricks ranged from 15.84% to 19.67%. According to Kumar (2002) and Indian Standard (1992) specification, the water absorption of ordinary burnt clay bricks should less than 20%. In the quantitative evaluations, both parameters corresponded to the relevant international standards and past researches, resembling up to R-20, and were within acceptable limit and also matched the normally used clay bricks, 0% to 30%; concrete blocks, 4% to 25% (Dhir and Jackson, 1996).

4.3.1 **Relationship between Total Water Absorption and Dry Density**

Figure 4.3 shows the relationship between total water absorption and dry density. This study found a negative relationship between water absorption and dry density i.e. when water absorption increased, dry density decreased.

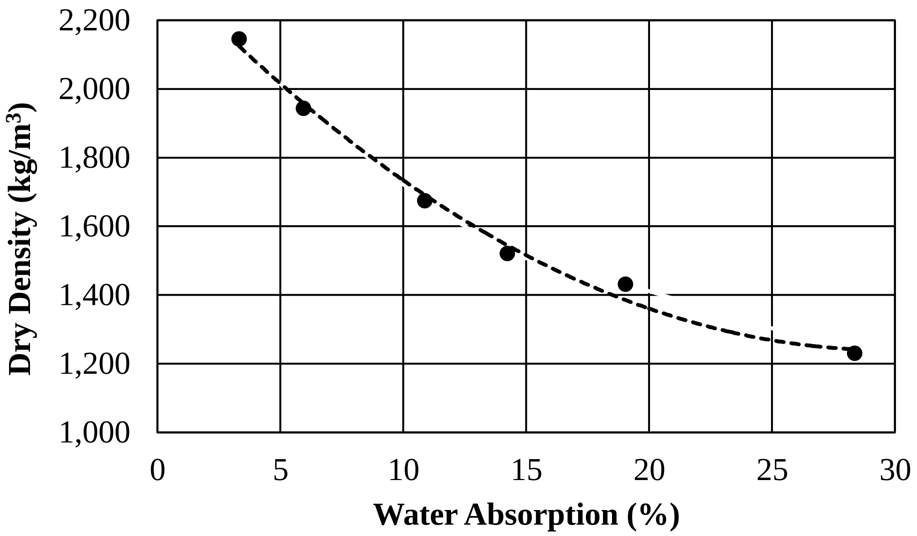

Figure 4.3: Relationship between Total Water Absorption and Dry Density

Decrease in density with variation of peat from 2150 kg/m^3 to 1230 kg/m^3 at 28 days increased the water absorption to about 25%. However, in term of the effects of peat on the bricks, when there was a decrease in density at 42.8%, the water absorption increased by about 25%.

The results also showed that the sample beyond a certain density values have significant reduction in total water absorption. The relation between strength and dry density are positive and strong, but the total water absorption is negative. In addition, when the strength increased, the density increased and water absorption decreased. Kumar (2002) reported that the increase in density of Fal.G. bricks was from 1172 kg/m^3 to 1230 kg/m^3, while water absorption decreased by about 19%. In the bricks, water absorption increased from 14% to 19%, while dry density decreased from 1520 kg/m^3 to 1430 kg/m^3, and then water absorption increased from 19% to 28% dry density decrease from 1430 kg/m^3 to 1230 kg/m^3. The trend was very obvious because the peat absorbed comparatively more water than other soil. Figure 4.3 shows the values of coefficient of relationship using statistical method, which shows negative values (0.99) of coefficient for the samples studied.

4.4 Brick Dry Density

The brick density is a vital aspect in determining the quality of blocks. There are different ways to determine the density. Brick dry density is most often indicated by the oven-dried value when dried to 65 ± 5°C within the period of 48 hours. The methodology of testing was discussed in Chapter 3. For all brick specimens, three samples were tested in each mixture. The test results are plotted in Figure 4.4. There is a negative relationship between dry density and peat content, in which the values of coefficient of relationship using statistical method was found to be 0.98 for the samples studied.

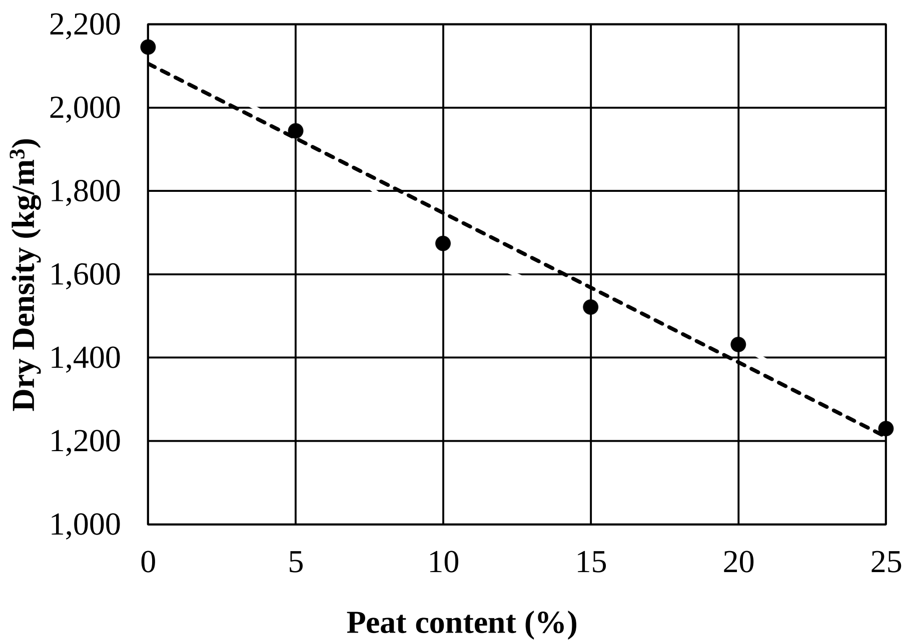

Figure 4.4: The relationship between variations of peat and dry density

The test results in Figure 4.4 point out that the dry density of the brick sample are inversely proportional to the percentage of peat. However, for 25% peat, the brick dry density was about 43%, which decreased with peat content, to 33% with 20% peat, 29% with 15% peat and 22% with 10% peat and 10% with 5% peat, respectively within 28 days. The density of control mix is 2150 kg/m^3 by considering it as an average density of the brick.

The 20% peat content brick is 66% lighter than ordinary sand brick. This reduction is particularly favourable showing the potential of peat-content bricks for using it as a lightweight building material. Lightweight materials can reduce structural dead load, are easy to handle, can reduce transportation costs, provide better thermal insulation and increase the percentage of brick production per unit of raw material (Raut et al., 2011).

According to Kerali (2001), the decrease in bricks and blocks density could have been due to four factors associated with the inclusion of micro-silica, which are pore filling effects, decreased homogeneity, decreased binding and increasing voids. In this case, the above factors helped in reducing the peat based bricks density.

The variation of dry density of concrete block containing petroleum-contaminated soils was investigated by Hago et al. (2007), which were found between 1300 kg/m^3 to 1480 Kg/m^3. Laurent et al. (2000) investigated the density of lateritic soil bricks and found in the range of 1640 kg/m^3 to 1660 kg/m^3. Deboucha (2011) in their study found that the dry density of peat added brick varied between 1633 kg/m^3 and 1895 kg/m^3 according to 20% to 30% cement content. In this study, the dry density varied between 1520 kg/m^3 and 1940 kg/m^3, thus it can be concluded that dry density of peat added bricks decreased linearly according to the peat content.

4.5 Total Volume Porosity

The porosity of bricks is an important property in this test. In comparison to other molded building materials, the porosity of brick is attributed to its fine capillaries and the moisture transport rate is ten time faster in brick due to virtue of its capillary effect (Deboucha, 2011). During day time, the moisture of bricks is released, and re-absorbed at night time. It is an important factor of building materials with respect to its application and performance.

In literature regarding concrete, (Neville et al., 1995) broadly defined the relationship among materials porosity and quality. The capillary porosity; that is often the most predominant aspect, is believed to be function of the water-cement ration and the degree of hydration achieved (Sjostrom, 1996). The volume of porosity can be measure directly or the water absorption value may be convert volume basis porosity by the following relationship:

$$n = \frac{(WA)\rho}{100\rho_w} \qquad 2$$

Where n = volume porosity

ρ = brick dry density (kg/m^3)

ρ_w = density of water (kg/m^3)

WA= water absorption (%)

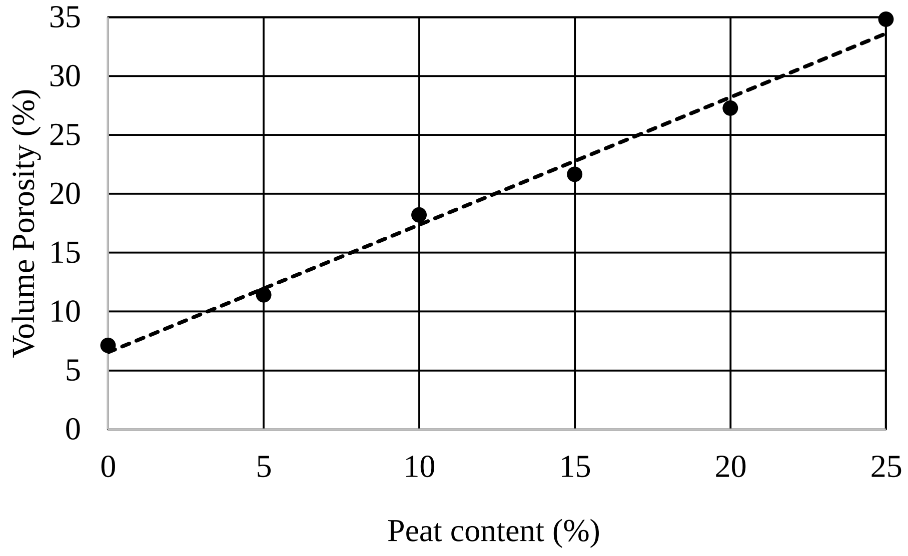

Figure 4.5: The relationship between variations of peat and volume porosity

The volume porosity result of the tested brick is illustrated in Figure 4.5. The obtained results showed that the porosity ranged between 27% to 37% with 20% to 0% peat content and 34.83% with 25% peat content within 28 days curing period. Figure 4.5 also shows an increase in porosity when the peat content was increased, in which the porosity at 28 days increased by about 82.5%. Dhir and Jackson (1996) reported that materials that have above 30% porosity are considered to be highly porous. The 20% peat content bricks had 27.27% porosity, which is less than 30 percent. All the bricks examined possessing up to 20% peat content can therefore be considered to be of low porosity.

4.5.1 **Relationship between Dry Density and Volume Porosity**

The relationship between dry density and volume of porosity was examined using the results, as illustrated in Figure 4.6. The results showed that the decrease in density increases the total volume porosity.

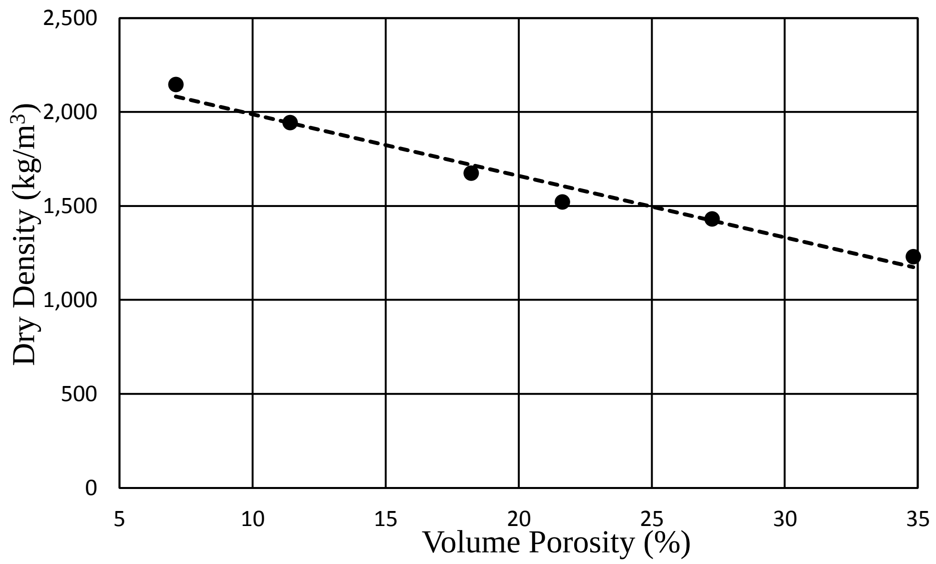

Figure 4.6: The relationship between the Dry Density and Brick Porosity

The coefficient of relationship was found 0.97 in mixture of 25% to 0% peat content under 7 MPa compaction pressure. These statistical values indicate that there was a very strong negative relationship existing between them. All the tested brick samples showed that the decrease in dry density was associated with an increase in porosity.

4.6 Compressive strength on Compressed Peat Added Brick

One of the most significant engineering properties of bricks is the compressive strength. On the basis of the value of the compressive strength of a brick, it's mechanical and other valuable qualities are judged (Rigassi, 1995; Young et al., 1998). Spence and Cook (1983) stated that the compression decreases the amount of voids and increases the inter-particle contact within a brick. It causes increase in density, and higher density always shows higher strength (Gooding and Thomas, 1995).

General, reactivity of the materials to water is dependent on the CaO to SiO_2 ratio. Higher the ratio, the more hydraulically reactive the material will be. As seen in Table 3.2, it is apparent that the OPC contained 66.23% of CaO, 21.60% of SiO_2, which can be categorized as hydraulic materials.

The hydraulic materials, when in reaction with water, could develop rapid initial strength gain. The siliceous sand had major oxide compounds of 70.04% SiO_2, 19.20% of Al_2O_3 and 2.15% of CaO as shown in Table 3.2. The major silica (70.04% SiO_2) and alumina (19.20% Al_2O_3) from the total oxide compound of siliceous sand cannot be considered because of its chemical inertness and the sand particles are too large for secondary pozzolanic reaction. Rather, siliceous sand functions as fillers for the void spaces in the stabilised soil, providing sufficient solid particles in the stabilised soil to enable cementation bonds to form and unite. Such bonds are stronger than the physical ones. These bonds are strong enough to resist any unlimited thixortropic expansion that normally occurs, in which the bond between clay particles in a soil and the OPC hydrates is thought to be of the chemical type (Herzog and Mitchell, 1963; Ingles and Metcalf, 1972).

Peat mainly contents 93.00% CO_2, 3.15% SiO_2 and 0.850% $Al_2O_{3,}$ as shown in Table 3.2. Carbon dioxide takes the majority of the peat compound, while the lower percent of silica and alumina means that very few amounts of clay particles exist in peat soils. The test method and factors considered throughout compressive strength evaluation of peat based compressed brick sample has been discussed previously. The procedure of brick sample production has been discussed in Chapter 3 (Section 3.4.1). The failure stress of the bricks was measured as normal. The dimension of brick sample used for compressive strength was 70 mm x 70 mm x 70 mm. For all samples tested, standard methods of British Standards Institution (1985) were used throughout the experiment.

4.6.1 **Effect of Varying Peat Soil Content on Compressive strength**

The content of peat was taken on the admixture according to effect of peat on strength. Low peat content attained high strength but as a new material, it had become uneconomic, whereby more than 25% of peat content on admixture attained very low strength, and does not satisfy any standard.

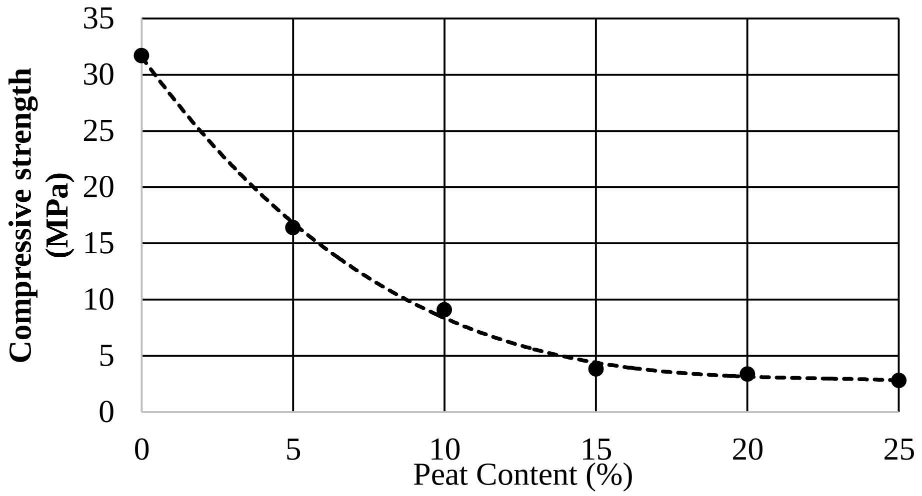

Figure 4.7: Relationship between compressive strength and percent of Peat content

The compressive strength of bricks was greatly affected by peat, as illustrated in Figure 4.7. The presence of peat (R-5) contributed approximately half of its strength and then progressively decreased with percentage of peat content. The compressive strength range for R-5 to R-25 was between 16.40 MPa and 2.80 MPa. The strength significantly increased when the cement content curing period increased. The compressed products gained strength when the curing period was increased because of the pozzolanic reaction in the binder which consolidated the materials progressively. It was known that water is required to activate pozzolanic reaction.

In conventional bricks, compressive strengths of compressed stabilised blocks were found to be no more than 4 MPa. Thus, for some building authorities, author recommend that compressive strength within the range of 3–5 MPa (non-load-bearing) and 5–10 MPa (load bearing) may be sufficient for construction (Arnold et al., 2004; Johnston, 2010; Raut et al., 2011). Some also recommended that minimum values are from 1.2 MPa (Lunt, 1980), 1.4 MPa (Fitzmaurice, 1958) and 2.8 MPa (International

Labour Office, 1987). Adam and Agib (2001) in their study compared the practical value of compressive strength of some common bricks and blocks, and found that the compressive strength of compressed stabilised earth blocks was in range of 1MPa and 40 MPa, while that of the light weight concrete blocks was in range of 2MPa and 20 MPa.

According to Turkish Standard Institution (1985), the minimum compressive strength of masonry units for non-load bearing and load-bearing are comparatively lower with corresponding values of 2.5 and 5.0 MPa. In British Standard, the minimum requirement for pre-cast concrete masonry units and fired clay blocks is 2.8 MPa, while for brick 5.2 MPa, where the building is considered as light load. According to the Indian Standard (1992), bricks are classified into eleven groups, based on their average compressive strength. According to this classification, the minimum compressive strength of brick should be 3.5 MPa.

According to literature (Chapter 2 Section 2.8.1) and above mentioned discussion, compressive strength values vary across wide-range, from country to country, and from author to author. The experimental values obtained here, however, are comparable with most current standards. The experimental values (sample R-25) are higher than 2.3 MPa, which is minimum strength, as indicated by the standards (Anfor, 2003; Inorpi, 2004) and also according to Australia Standard (1984) can be used in non-load bearing and load bearing masonry units for low cost and lightweight building construction.

According to American Society for Testing and Materials (ASTM C 129), the sample maximum R-15 can be used for the non-load bearing masonry units, where the minimum value is 3.50 MPa. The samples R-10 satisfy the minimum value 7.0 MPa as building material to be used in the structural applications, as described in British Stadard Institution (1981), which is also close to ASTM C 129 for load bearing.

The compressive strength of the samples (R-10 to R-25) doubles for 7 and 28 days curing period. The result showed that 15% peat content for all the structures can be chosen, as dictated from the above discussion, the content of peat soils less than 15% would not be economic for the purpose this study and did not lead to sufficient results when utilizing more than 20% of peat soil in the mixture.

4.6.2 Effect of Curing on Compressive strength of Peat Added Bricks

Curing of peat based compressed brick was carried out to determine the effect of various varying parameters on the compressive strength properties of bricks. The initial curing of the sample was enclosed with plastic bag for a day, and then moved for curing in moist cured room for a period of 28 days. The hydration process of cement is a long reaction, and continuously modify through days, months and even years, eventually increasing its mechanical strength (Zhang et al., 2012).

The effect of varying curing period on brick strength was examined experimentally to check, whereas peat based compressed brick sample was stabilised with various peat content percentage. The compressive strength of the tested bricks progressively increased from day 7 to day 28. The curing was attributed to the chemical reactivity of OPC cement super plasticiser and the binder with water, as well as the role of siliceous sand as filler in the stabilised soil. When the cement content and curing period increased, the strength increased as well. Compressed products gained strength when the curing period was increased because of the pozzolanic reaction in the binder consolidated the materials progressively. To check the further reactivity of an organic soil, additional 60 days and 90 days curing were done for examining the compressive strength of bricks with 15% and 20% peat content.

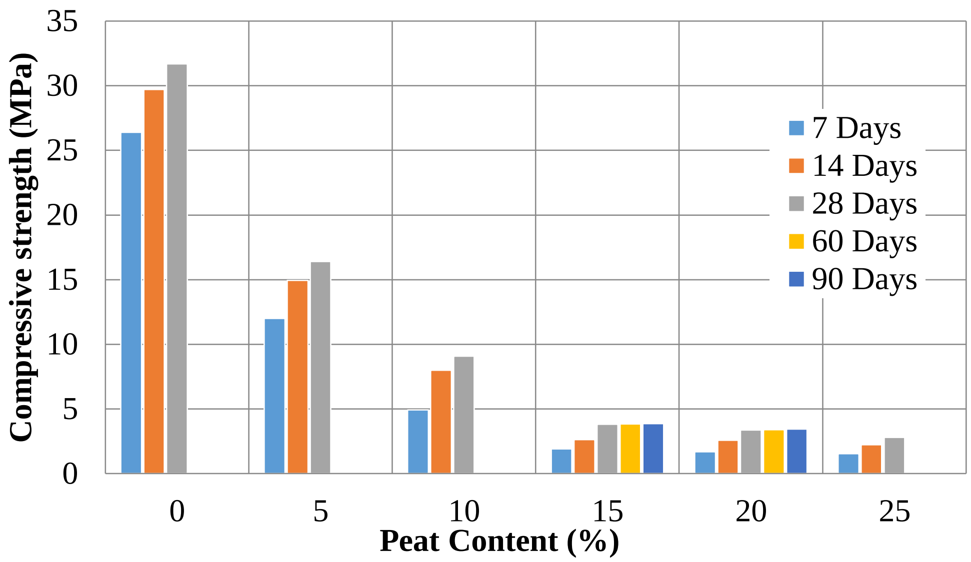

Figure 4.8: Relationship between compressive strength and curing

The plot of strength of brick against age and effect of curing is illustrated in Figure 4.8. It was observed that the strength of the brick increased with aging. The compressive strength of bricks with different peat level of 0% to 25% peat was found after 7 days to be 83%, 73%, 54%, 49%, 50%, 51% and after 14 days it became 94%, 91%, 88%, 69%, 76%, 74% respectively.

Meanwhile, the compressive strength in bricks with 0% to 25% peat level from 7 to 28 days was found to increase 17%, 27%, 46%, 50%, 50%, 49%, respectively. It was observed that within 7 days, the control sample (0% peat) gained more than 80% strength, but it decreased with the increasing of peat content up to 50%.

4.6.3 Relationship between Water Absorption and Compressive strength

This section discusses on the relationship between the total water absorption and compressive strength of the brick. The relationship of water absorption and compressive strength result obtained after 28 days is plotted in Figure 4.9. This figure illustrates a negative relationship between the total water absorption and compressive strength. The water absorption was found to increase, corresponding to the decrease in strength. The coefficient of relationship was found 0.96 as a power function at 28 days with 0% to 25% peat content.

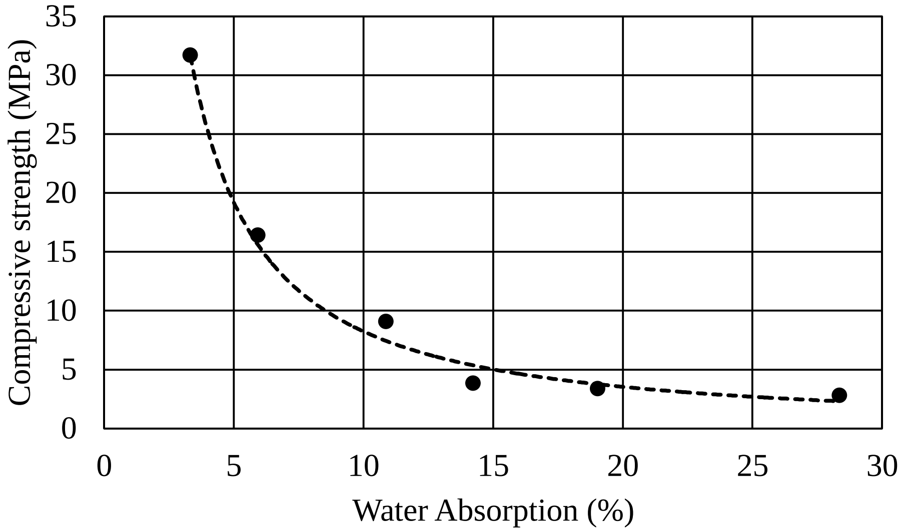

Figure 4.9: Relationship between compressive strength and Water Absorption

The water absorption rose with increasing peat content, as increasing peat content means reduction of sand content and decrease of silica, alumina. However, less strength means more voids and more water absorption for peat added bricks.

4.6.4 Relationship between Dry Density and Compressive strength

Figure 4.10 shows the plot of brick dry density against compressive strength. The results showed that a positive relationship existed between dry density and compressive strength for different peat content. The graph illustrates that the increase in density is accompanied by a corresponding increase in strength. The positive coefficient of relationship values between brick strength and density was found to be 0.99 with brick samples of compacted 7 MPa pressure within 28 days.

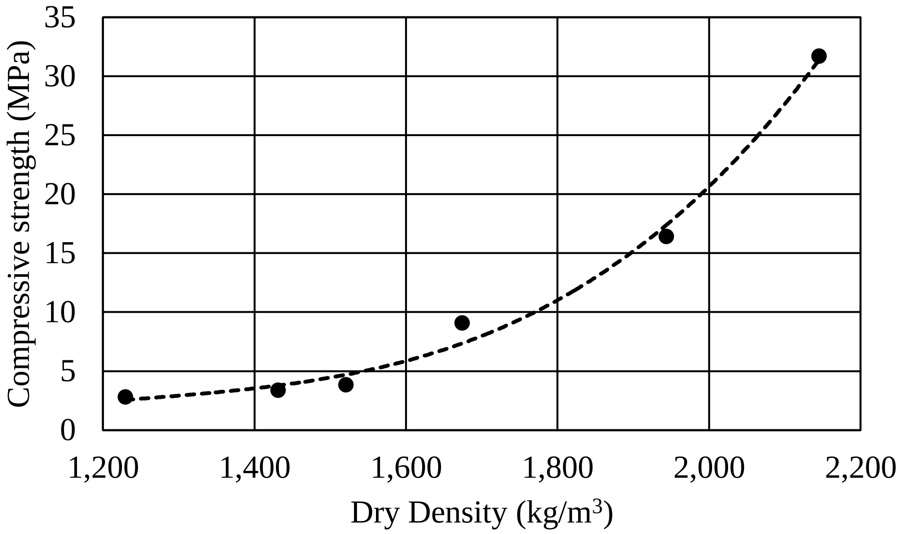

Figure 4.10: Relationship between compressive strength and Dry Density

The relationship between the brick's dry density and compressive strength has also been widely reported in comparable materials (Jackson and Dhir, 1988). The values of dry density for more usage of building materials are between 2250 kg/m^3 and 2800 kg/m^3 for fired clay bricks, between 1700 kg/m^3 and 2100 kg/m^3 for calcium silicate bricks, and between 500 kg/m^3 and 2100 kg/m^3 for concrete blocks.

These values are definitely comparable compared with those obtained experimentally in this study. The test result showed that dry density of bricks between 1200 kg/m^3 and 1600 kg/m^3 is particularly favourable, showing the potential of peat-content bricks in the practice as a lightweight building material.

4.6.5 **Relationship between Compressive strength and Volume Porosity**

A negative relationship is illustrated in Figure 4.11 between the compressive strength and total volume porosity. This figure shows that increased porosity is accompanied by a decrease in strength. The coefficient of relationship was found 0.98 for the brick with different peat content.

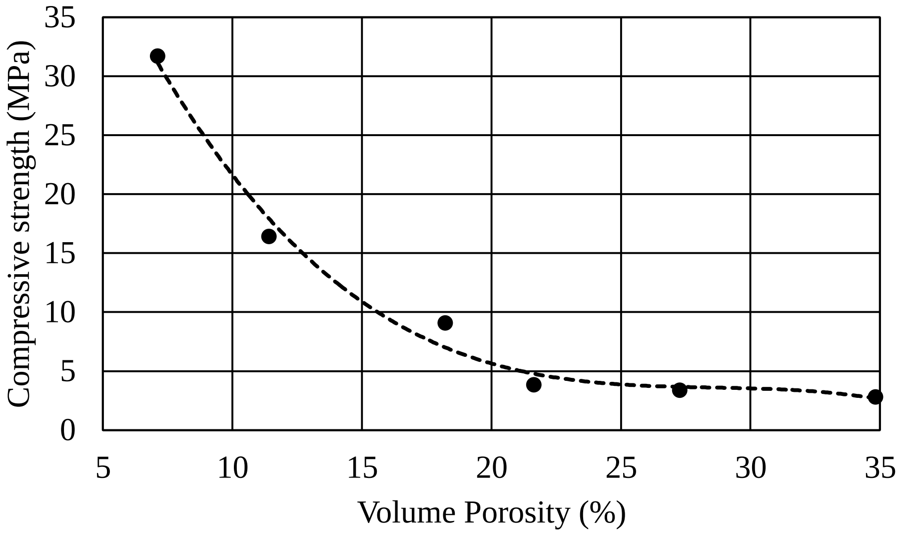

Figure 4.11: Relationship between compressive strength and Volume Porosity

The porosity effect of utilizing peat was from 11.42% to 34.83% and 25% peat as having highest porosity. According to Kerali (2001), the decrease in compressive strength with increase in porosity can be explained as the compressive strength of a block or brick is limited by brittle fracture.

Thus, it is sensitive to individual flaws in the brick sample under test, and may face discontinuity due to the presence of pore or voids structure between solid phases in the brick. The higher the amount of voids, the weaker the block will be. Large size of coarse fractions in a brick can also create flaws in it. The combination of such large particles and voids in a block can make it more susceptible to brittle fracture failure. In this study, it was observed that peat and the sand matrix did not show any uneven surface or sudden brittle fracture, even beyond the failure loads.

4.6.6 Comparative Relationships of Compressive Strength, UPV values and Flexural Strength

The comparative relationships among the compressive strength, UPV values and flexural strength are shown in Figure 4.12.

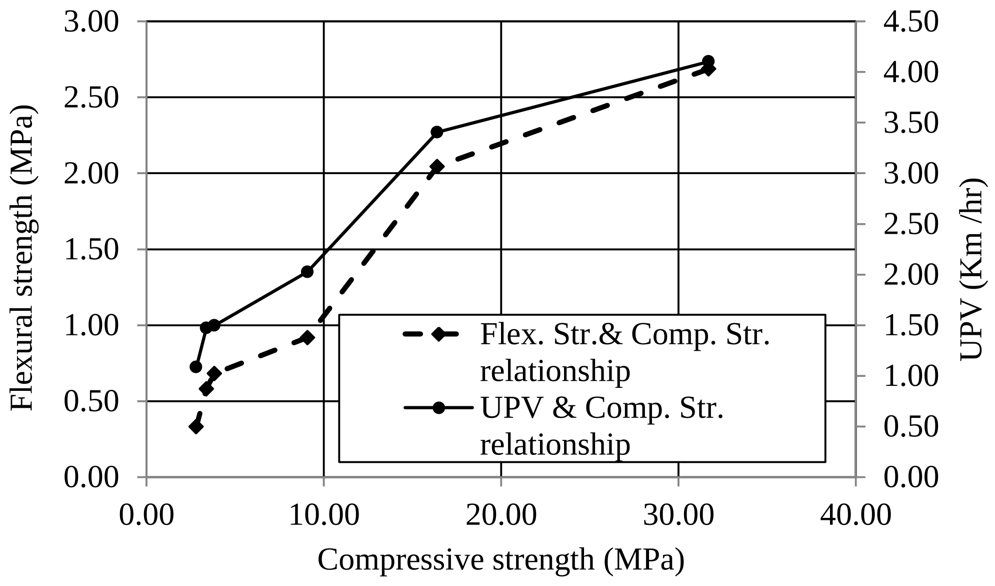

Figure 4.12: Comparative relationships of Compressive strength, UPV values and flexural strength

The UPV is taken on the flexural strength brick samples having its 220 mm path length according to British Standards Institution (1997). The UPV values are lower for the voids caused by peat.

The reduction in the strength values causes the UPV to be decreased. Non-destructive UPV test results indicate that the wet compressive and flexural strength values of peat added bricks may approximately be determined without a destructive testing which gives a qualitative assessment of brick.

A linear relationship between the two parameters compressive strength and the flexural strengths of bricks illustrate in Figure 4.12. The positive coefficient of relationship values between brick compressive strength and flexural strength was found 0.94. These statistical values indicate that there is a very strong positive relationship exists between them.

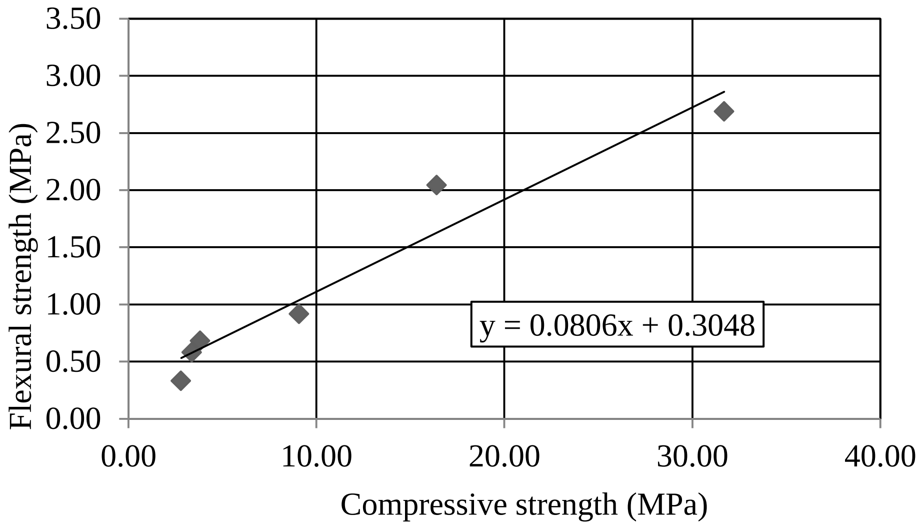

Figure 4.13: Relationship between Compressive strength and flexural strengths

The splitting stress at which the brick sample may crack is a form of tension failure. The relationship between the splitting stress and percent of peat content illustrate in Figure 4.1 (appendix A). Minimum flexural strength described in British Stranded Institution (1981) is 0.65 MPa for building materials can be used in structural applications.

The flexural strength of R-20 samples (0.58MPa) and bricks with maximum 15% peat replacements satisfy the British Stranded Institution (1981). Hence, these peat added bricks can to be used in structural applications.

4.7 Durability of Peat Added Bricks: Prediction of Erosion Resistance

4.7.1 **General**

Materials greatly influence the performance of a building system. A high performance building requires high-performance building feature, including durability, energy efficiency, occupant productivity and life-cycle performance (Bomberg and Onysko, 2008; Trinius and Sjöström, 2005).

The main problem that often occurs in the use of compressed bricks is not the strength but rather its’ durability. In addition, the bricks are less durable than conventional building materials. The low durability of the materials is more noticeable when the bricks are facing local conditions (i.e. rain, frost and wind). The impact of raindrops driven by wind is the main cause of erosion. Heavy rainfall is also a major factor of erosion because rain drops hit the wall surface at an acute angle (Heathcote, 1995).

Laboratory testing was carried out to investigate the effect of climatic. The erosion of earth walls due to driving rain was considered proportional to the amount of rain impacting the vertical surface, which was reasonably predicted based on laboratory tests and an assessment of climatic site conditions. This investigation aimed to examine the effect of wind-driven rain erodibility on peat added brick unit, and whether or not peat has potential to be used as a brick material, which can be predicted in particular climatic locations, based on the laboratory simulation performance.

The compressive strength, density and water absorption properties were tested. The compressive strength was found to be 9100 kPa for 10% and 3850 kPa form 15% peat added bricks. Compressive strength of 20% and 25% peat added bricks are 3350 kPa, 2800 kPa. To check the wind drive-rain erosion and erodibility, these four types of composition were taken to test.

4.7.2 Effect of Density and Moisture Content on Erosion Resistance

The dry densities of the tested bricks were 1230, 1430, 1520 and 1670 Kg/m^3 corresponding to 25, 20, 15 and 10% peat respectively. The brick dry density greatly varied with the percentage of peat content. The raw material peat had high water content and it absorbed more water than sand. The water absorption (% volume) for 25, 20, 15 and 10 percent peat contents were 34, 27, 21 and 20 percent, respectively. The percentage of porosity increased 15%, corresponding 0% to 15% peat and 14%, corresponding 15% to 25% peat respectively.

The in-suite moisture content for compressed bricks with peat was greatly influenced by peat percent, causing consequence on durability. In this laboratory based experiment, the effect of in-suite moisture of test bricks was allowed as an increase in the proportionality constant.

4.7.3 Peat Effect on Bricks Erosion

Twenty numbers of brick samples (dimension 100 mm X 70 mm X 220 mm) were examined for erosion test. The erosion test results of the tested bricks are presented in Table 4.1.

Table 4.1: Brick erosion test result

Type of Brick	Time (minutes)	Depth of Erosion (mm)	Rate of Erosion (mm/minute)
Compressed brick with 10% peat	90	0	0.00
		0	
		0	
		0	
		0	
Compressed brick with 15% peat	90	1	0.017
		2	
		1	
		2	
		1.5	
Compressed brick with 20% peat	90	2	0.021
		2	
		1.5	
		2	
		2	
Compressed brick with 25% peat	90	3	0.028
		3.2	
		2.5	
		3	
		2.5	

The erosion depth of 10% peat content bricks was found insignificant. It is said that bricks containing up to 10% peat content generally do not experience any significant erosion within its designed service life. Table 4.1 illustrates the result from 15% peat content bricks. As seen in Table 4.1, an increasing percentage of peat from 15 to 25 percent that means 10% peat conveys the erosion rate around 65%. Figure 4.14, shows more clearly of these trends, where depth of erosion and erosion rate both are presented against weight percentage of peat replacement with sand.

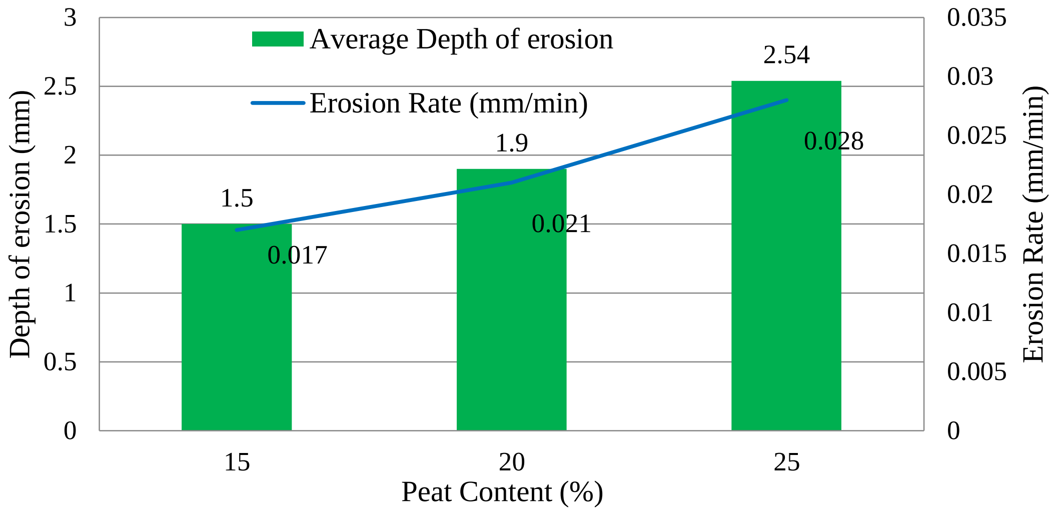

Figure 4.14: Erosion depth and rate against weight percentage of peat replacement with sand

The increasing erosion rate for 5% peat increased to 24%, then 33% for the same percentage of peat increment, because the erosion was greatly influenced by overall peat in brick content. The erosion rate of tested bricks in their testing period is shown in Figure 4.15. This illustration also demonstrates the relationship between the percentage of peat content and the time elapse at erosion, which indicated that the time at erosion increased strongly with peat content.

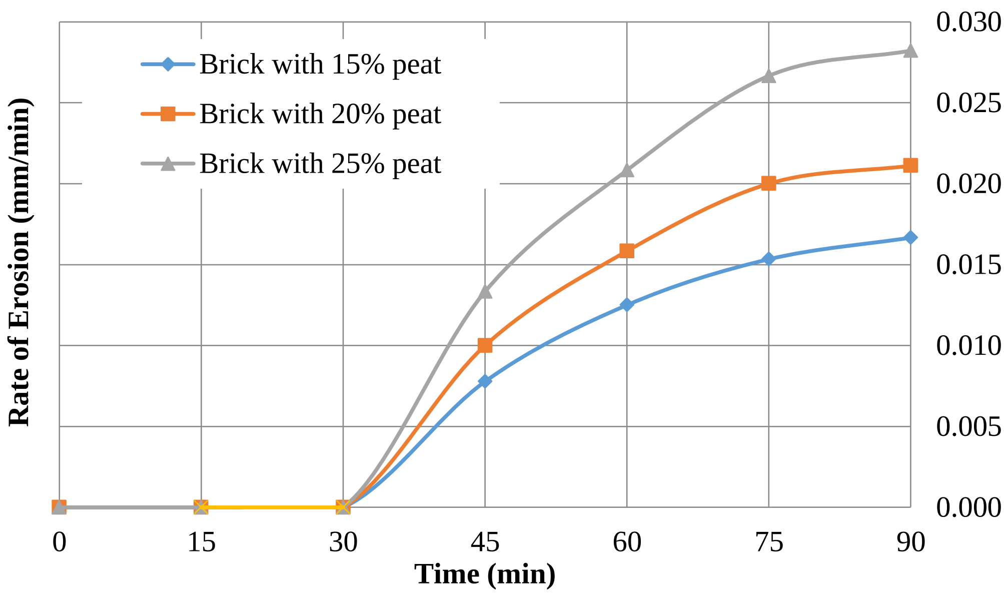

Figure 4.15: Relationship between Rate of erosion (mm/min) and Elapse time (min)

In the initial stage of test, the erosion rate was very slow and the erosion rate increased with time. Within the first 30 minutes no erosion depth was found. Subsequently, the erosion depth increased with time. This phenomenon of the bricks occurred due the peat content adjacent to the brick surface was lesser than the inner ones. Afterward, the top soil of the brick surface was eroded, and the erosion rate rose substantially because the interior peat content of the bricks contributed to more erosion rate.

The erosion curves for compressed bricks with different peat percent displayed the similar trend, but vary in values. Figure 4.16 presents the appearance of the erosion pattern in the bricks.

Figure 4.16: Appearance of the eroded bricks

This erosion pattern was similar to the pattern that Heathcote and Moor (2003) found in their field investigation in actual weather condition for wind driving rain. The maximum depth was measured for the test result and the depth of erosion was measured using a flat-ended rod.

4.7.4 **Allowable Wall Erosion**

The erosion depth found from the lab test indicated that the average erosion depth to be predicated of its service life but can be multiplied by a factor of safety. Heathcote and Moor (2003) reported factor of safety as two in experimental investigation, and stated that local areas of erosion will occur to be 50% greater than that the calculated value. Table 4.2 shows the maximum depth of erosion of peat based bricks with different peat percentage after 90 minutes.

Table 4.2: Maximum erosion loss of tested bricks on its service life

Type of Brick	Depth of Erosion	Predicted Average Loss = 2× Erosion depth	Predicted Maximum Localized Loss =1.5 × Predicted Average Loss
Brick with 15% peat	1.5	3	4.5
Brick with 20% peat	1.9	3.8	5.7
Brick with 25% peat	2.54	5.08	7.62

The erosion of walls posed a structural problem, when the walls were not much thicker. Erosion is also an aesthetics problem. For this experiment, the categories between the acceptable levels of erosion and acceptable classes of surface finish according to Heathcote and Moor (2003) are adopted

Class of surface	average surface erosion (mm) over a 50 year	local areas of erosion (mm)
Class1	4	6
Class 2	8	12
Class 3	12	18

It was found that the 15% and 20% peat added bricks had much erosion resistance and had a good surface finish to use without any significant surface finish. The 25% peat content bricks required a good surface finish to use in this climatic region.

4.7.5 Regression Analysis

Regression analysis was done for the test results on the bricks with peat as a function of the time elapse till 90 minutes. The optimum regression quadratic that best fitted the tested data was a function form of

$$Y = ax^3 + bx^2 + cx + d \qquad 3$$

where, brick erosion rate (mm / min) is denoted by Y and x indicates the erosion time (min). Constants a, b and c are material parameters, calculated by using the regression analysis, as presented in Table 4.3.

Table 4.3: The constants of erosion rate equation for different peat content

Peat (%)	Value		Constants				Norm of residuals
	Y	x	a	b	c	d	
15	0.017	90	-9.1907e-008	1.3186e-005	-0.00026186	0.0002235	0.002417
20	0.021	90	-1.2117e-007	1.7313e-005	-0.00034752	0.0003240	0.002996
25	0.028	90	-1.5866e-007	2.2757e-005	-0.00045619	0.0004219	0.003984

It was observed that the elapse time at 30 minutes had no erosion. Thus x values would be either equal or less than 30, while Y would always be zero.

4.8 Effect of Thermal Performances of Building Bricks due to Peat Addition

4.8.1 **General**

Thermal protection features with reasonable energy consumption, satisfactory thermal comfort conditions and low operational costs are emerging needs in building construction (Turgut and Yesilata, 2008). Therefore, energy saving becomes an immediate requirement in construction industry. Energy saving is an important issue in the world because of both economic and environmental concerns.

Generally, buildings and its' related compartments consume 33% of produced energy around the world. In this regards, half of the energy is lost through walls (Sutcu and Akkurt, 2009). A major factor that contributes to the loss of energy through walls is wall thickness. The thickness of wall imposes higher costs to construction and reduces the effective living space. However, more recently the regulations for construction of buildings have been tightened and various boundaries for thermal properties and environmental mitigation have been put in place (Papadopoulos, 2005).

The aim of the work reported in this session is to investigate the effect of peat inclusion in the brick composites on the thermal properties and determine the effect of peat content in bricks on thermal isolation properties.

There is no available study on the quantification of thermal performance of peat cementation products. The thermo-mechanical performances of peat added bricks examined here are intended to fill the gap of knowledge to some extend in bricks production.

4.8.2 **The Thermal Behaviour due to Peat Addition**

In this study, the effect of peat accumulation on thermal transmittance of the sand brick was examined as a comparative analysis. Thus, the thermal transmittance of peat added brick samples (R-10, R-15 and R-20) were compared with the pure sand sample (present as R-0).

Figure 4.17 illustrates the experimental test result. The instant temperatures given in the Figure 4.17 present the water temperature in the adiabatic box, whose upper surface was enclosed by the corresponding bricks samples. The comparative analysis for the brick samples was made during cooling period. Figure 4.17 presents the average value of Time-Temperature curve and temperature obtained from the three similar types of sample (deviations not exceeding 3%).

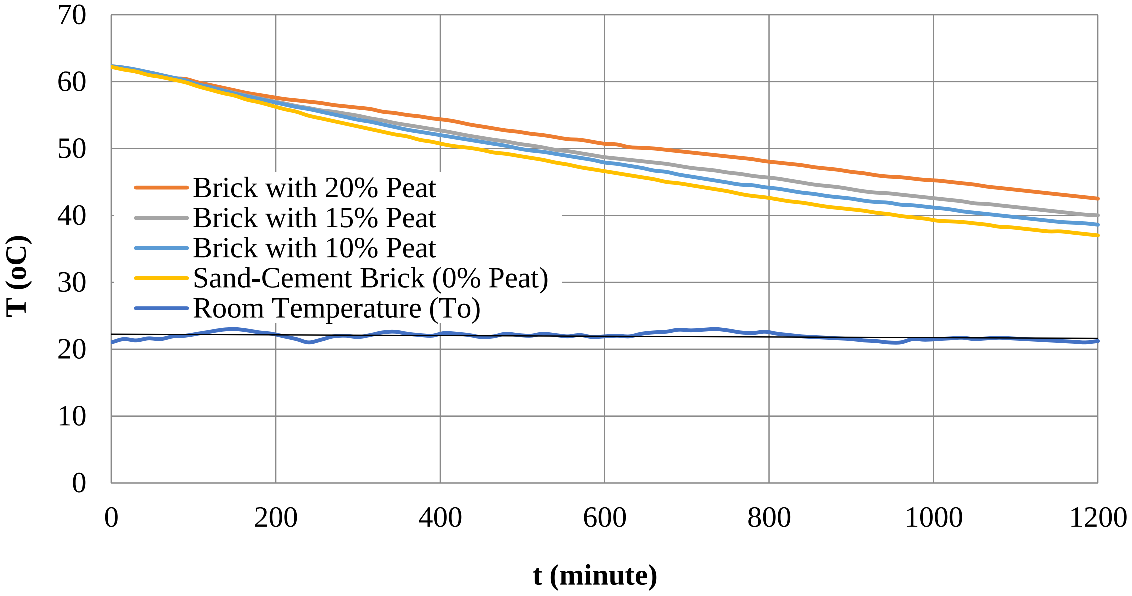

Figure 4.17: The transient temperature during dynamical thermal test

The instant cold room temperatures during the experiment were taken at three various places of the room and their average temperature values are shown in Figure 4.17. The average room temperatures differences for the entire sample were kept at ± 2ºC.

The solid trend line in Figure 4.17 shows that the average room temperature (T_o) at any instance throughout the test was constant.

The equilibrium temperature could not be attained although test was maintained for about 20 hours. At the early start of the test, the time–temperature curves for the tester illustrated similar behaviour. The temperatures abruptly reduced and then slowed down.

At the intermediate times in cooling rates, significant differences were observed from the brick samples. The largest heat loss rate among the sample was observed from the ordinary brick sample (R-0: no peat case). The thermal transmittance of the peat added brick became lower, which means the addition of peat improved its insulation property. It was observed that among the brick sample, the maximum of 20% peat content bricks illustrated the greatest insulation improvement bricks.

The higher instant value of temperature of the high content peat added bricks during the testing period were a good sign, but quantification as given below was also made. According to Yesilata and Turgut (2007) the samples can also be tested at various external and internal temperatures, preserving the same heat transfer mechanism. The experimental period are done 20hr to make fair comparison. The dimensionless temperatures values (T*) are defined for quantitative comparison.

$$T^* = \frac{\mathrm{T(t)} - T_0}{\mathrm{T(t{=}i)} - T_o} = \frac{T}{T_i} \qquad 4$$

where, T (t) = Water temperatures at the beginning.

T (t = i) = Water temperatures at any instant time of the experiments.

T_o = Represents the time-averaged temperature of the cold space.

The dimensionless temperature T* is the ratio of hot water exergy at any time at the beginning of the experiment (available exergy). The corresponding meaning is expressed for the hot water with known mass (m) and specific heat (Cp) as:

$$T^* = \frac{\varrho}{\varrho_i} = \frac{mc_p(\mathrm{T}-T_0)}{mc_p(\mathrm{T}_i-T_0)} = \frac{T}{T_i} \qquad 5$$

The differences in thermal performances are observed more clearly in Figure 4.18, where different values of dimensionless temperature T* with respect to time are illustrated.

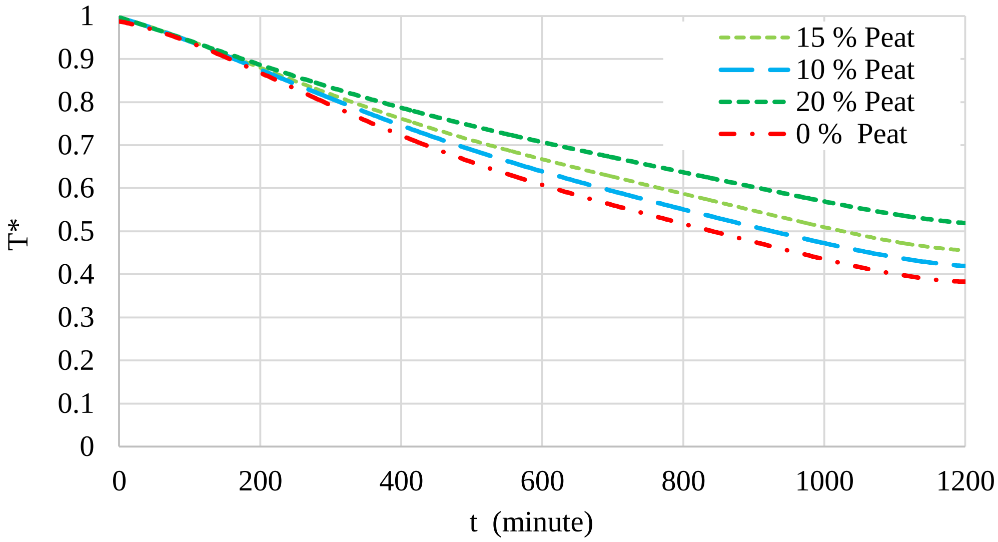

Figure 4.18: The transient temperature as dimensionless value during thermal test

Sum of the differences in *T** values allows comparing thermal transmittances of two different specimens. The percentagewise difference of thermal transmittances of any two samples can be calculated using the following equation:

$$X = \left[\frac{\left(\sum_{t=0}^{t=t_i} T_t^*\right)_1}{\left(\sum_{t=0}^{t=t_i} T_t^*\right)_2} - 1\right] \times 100 \qquad 6$$

where, t_i is the total experimental time, *t* of *T** is a dummy variable and subscripts *1* and *2* correspond to peat added bricks and ordinary brick (with no peat) respectively.

It can be easily quantified the effect of peat addition on the ordinary brick by determining the X value that means positive value indicate improvement by peat addition. The thermal insulation behavior of the sample are illustrate in Table 4.4.

Table 4.4: Test results on thermal insulation behaviour of the samples

Percent of Peat content	R-0	R-10	R-15	R-20
$\left(\sum_{t=0}^{t=t_i} T_t^*\right)$	52.28	53.44	54.30	55.52
X%	-	2.2	3.8	6.2

Table 4.4 illustrate that the peat addition in ordinary brick improves thermal insulation performance or makes lowers the thermal transmittance. The percentage-wise improvement of thermal insulation increase with increasing peat percent and it extent up to 6.2% for 20% peat content (R-20 sample).

4.8.3 **Effect of Density and Porosity on Thermal Transmission**

Figure 4.19 and Figure 4.20 illustrates the relations between the percentage-wise improvement of thermal insulation, porosity and dry density of bricks. It was evident that increasing the percentage of peat cause more porosity. The less percent of silica and alumina in the peat caused low strength during the chemical process, causing porosity in bricks.

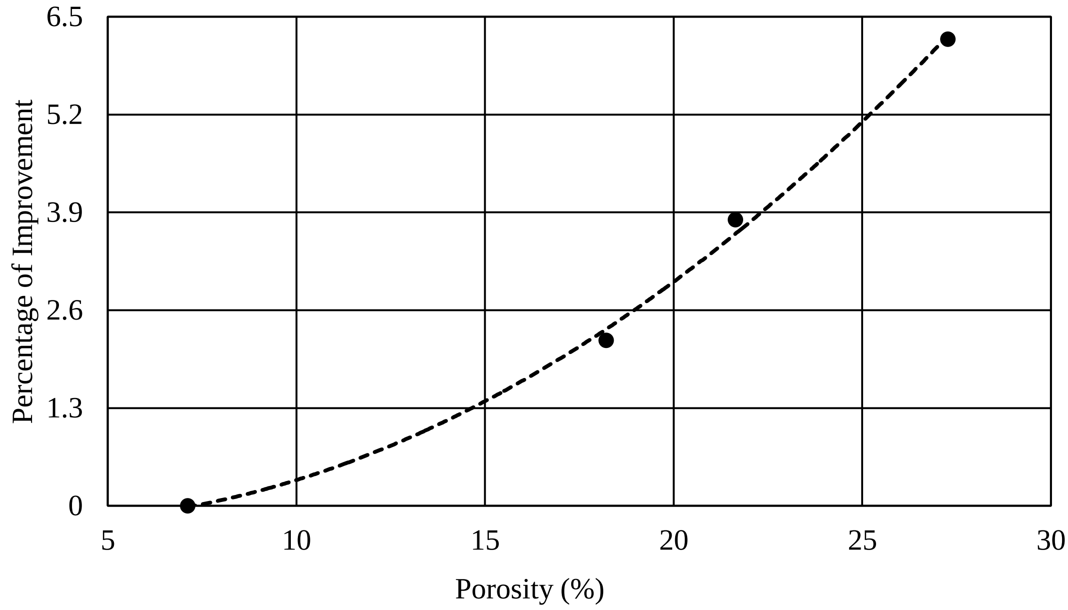

Figure 4.19: The relationship between the percentage-wise improvement of thermal insulation and porosity

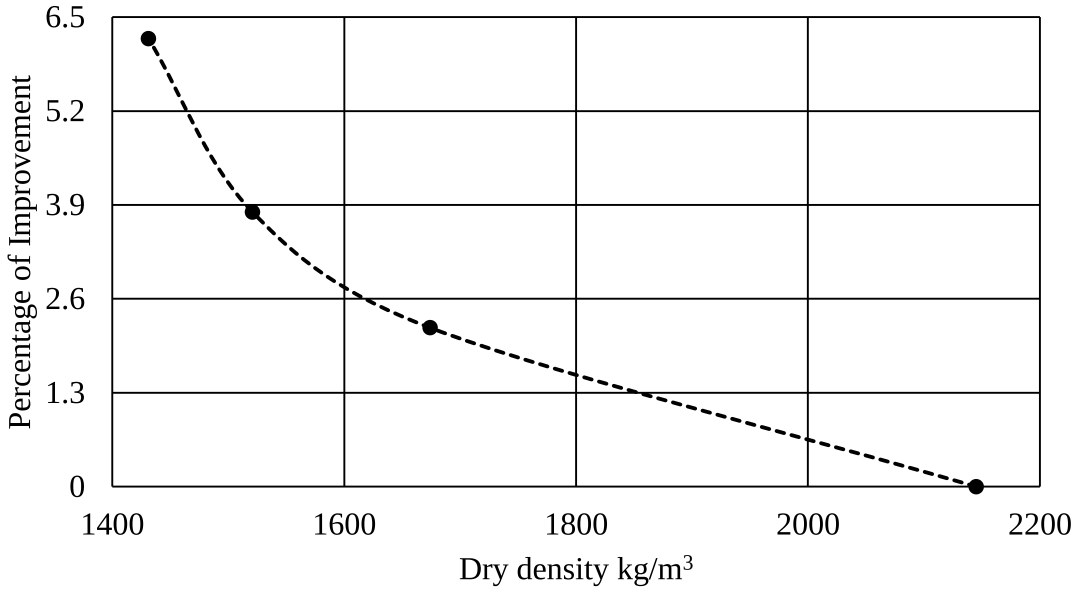

Figure 4.20: The relationship between the percentage-wise improvement of thermal insulation and Dry density

The results showed that the higher content of peat induced lower thermal conduction. This was because of the increase of air volume attained by the peat, a process that led to pore formation within the samples leading to poor thermal conductors, and hence, as good backup insulators. It can be concluded that thermal insulation of peat added bricks increased with decrease in density and increased porosity.

According to the literature as discussed in Chapter 2, the thermal insulation properties become lower if the density of bricks becomes higher. Phonphuak (2013) stated that light weight aggregates when mixed in concrete results in good thermal insulation properties as they posse high void ratio due to their porous nature. Therefore, by creating air-bubble or voids in the materials, lightweight materials with low thermal conductivity can be produced. As found in this study, the thermal behaviour of peat added bricks depends to the density. By lowering the density of bricks, a lower thermal conductivity can be achieved.

CHAPTER 5 : CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objectives of this thesis were to investigate the effect of peat addition on the engineering properties of the brick, durability and the thermal performance. This study technically demonstrates the feasibility of producing peat added bricks. To achieve these aims, the physico-mechanical properties of peat added bricks were examined. This study investigated and presented the findings from the engineering properties tests including compressive strength, flexural, splitting, UPV, total water absorption, volume porosity, dry density and other aspects which have effects on the thermal performance and erosion resistance of the peat-brick.

It was found that in the bricks with higher peat content have compressive strength higher than the recommended minimum value of 2.5 MPa. The effect of increase in peat content greatly affected the strength of bricks, which progressively decreased. It was found that for increase in peat content from 5% to 25%, the compressive strength decreased up to 82%. The compressive strength for R-5 to R-25 ranged between 16.40 to 2.80 MPa. Compressive strength and flexural strength of brick sample R-15 satisfied the minimum requirement for load-bearing masonry unit, which means that it can be utilized in structural applications. However the brick sample R-20 can be applied for non-load-bearing masonry units. Although 25% replacement of sand by peat achieved the minimum compressive strength of available compressed stabilised earth bricks, the water absorption and porosity were found to significantly affect their durability. It can be therefore being concluded that the use of peat contents when increased from 15% to 20% is more suitable for peat added brick.

This study also investigated the effect of varying curing conditions on the performance of peat added bricks. Bricks were cured for duration of 7, 14, and 28 days.

It was found that the compressive strength increased with the increasing curing time by about 52%. It can be concluded that the curing of bricks can be done in such manner that allows continued presence of moisture to complete the hydration reaction of stabilisers.

The investigation regarding the effect of varying peat content on dry density, it was found that the density decreased with the increasing peat content. Moreover, the density was found to decrease with the decreasing curing periods. Increasing peat content from 5% to 25% showed that the density of peat added bricks decreased to 37%. Replacement of peat as aggregate 20 percent (R-20) reduced the density of sample by 33%, which can provide 66% lighter brick compared to the concrete brick. The conclusion here is that increase in peat makes lighter peat added bricks.

It was also found that a strong positive relationship existed between density and the 28 days of compressive strength, where the coefficient of relationship was 0.99. It can be concluded that decrease in density can result in decrease compressive strength. However, very high densities could result in flaws during brick laying and transportation. It was also found the peat added brick was about 15% to 20% lighter than solid clay or sand bricks. In term of economy, it can reduce the cost of building by reducing the weight of constructions elements.

Moreover, increase in peat content resulted in increase of total water absorption. The overall increase in total water absorption with increase in peat from 5% to 25% ranged between 14% and 68%. Generally, the lesser water a brick absorbs, the better its performance is expected to be. It can be concluded that total water absorption is a valuable indicator of a brick’s quality, as it can be used to estimate the volume of pore voids.

From the results, it was evident that the total water absorption values reached up to 20% peat content bricks, lower than the recommended maximum value of 20% (Indian standard). The conclusion here is that percentage of peat content in peat added bricks is an effective way to control the total water absorption.

Negative relationship was also found to exist between total water absorption and density, where the coefficient of relationship was 0.99 with peat content. Moreover, the volume porosity varied between 11.42% and 34.83% when the peat ranged from 5% to 25%. It was evident that a very strong negative relationship existed between total volume porosity and compressive strength, where the coefficient of relationship was 0.98. The conclusion here is that the greater the pores higher the void. Large coarse soil particles in bricks can create flaws and weaken the bricks. The siliceous sand and peat soil fraction having a particle size not more than 2 mm for increasing sand matrix peat soil fraction greater than zero provided comparatively better results. The effect of peat added to the sand matrix did not exhibit any uneven surface or sudden brittle fracture, even beyond the failure loads.

In this study found a negative relationship between brick dry density and total volume porosity, where the coefficient of relationship was 0.97. Decrease in density was about 37%, which resulted in the increase of total volume porosity by about 67%. The materials that have porosity above 30% are considered to be of high porosity. The 20% peat content bricks had 27.27% porosity, i.e. less than 30 percent. All the examined bricks having up to 20% peat content can therefore be considered to be of low porosity. It is therefore recommended that proper moist curing be used as a way to reduce the total volume porosity in peat added bricks.

It was found that peat added bricks have sufficient rating for erosion resistance. Wind driven rain erosion till 20% peat content of peat added bricks obtained the predicted maximum localized loss of not more than 4.5 mm, whereas the recommended value is 6 mm. Bricks with maximum 20% peat content exhibited expectable erosion, while 33% higher erosion was observed in bricks with 25% peat content. No erosion was observed within the first half an hour. Within the next thirty minutes, maximum erosion of around 75% was observed on the bricks. All bricks showed a similar erosion pattern. The mixing quality is an important factor to erosion rate. The bricks made from peat have a great potential of erosion resistance to withstand extreme weather, which is suitable for tropical rainforest climate areas. The bricks with 25% peat content can be used as good surface finish, but requires high maintenance. It can be concluded that the peat added brick are erosion resistant, but only those having up to 20% of peat content.

It was also evident that there is a positive effect in terms of thermal transmission in peat added bricks. The peat added bricks showed a decrease in thermal transmission 42.5^{o}c to 37^{o}c at peat content of 0% to 20% after 20 hours of thermal test. Thermal insulation was improved by 6.2 % compared to the sand brick (0% peat). From the experimental results curve, it was found that maximum improvement was 63% from R-15 to R-20 bricks and the maximum differences values with sand brick between each point was 42.5^{o}C whereas it was 37^{o}C for sand brick. It can be concluded that the peat added bricks used for partition have good thermal insulation.

5.2 Recommendation for Further Application

This study, evaluated the quality of peat-added brick however, further research is required. The findings from this research have flagged up a number of new questions for future research. Following are the areas for further research:

The construction of houses using local materials in the developed countries is marginal and limited because it is complex to standardize the composition of materials for varies locally additives. Therefore, detailed further study is required to figure out complete guideline for the local peat soil from different regions of Malaysia to prepare eco-friendly and cost-effective peat added bricks.

The experiments have shown that heavy rain, even for a short time, may cause more damage than prolonged lighter rain. Therefore, knowledge on the local weather conditions and analysis of meteorological data can provide useful information on the erosion risk and for choosing appropriate surface finish. Therefore, proper investigation on the use of peat is required to define the erosion resistance in actual climatic region, to identify accurate field erosion for elevating the performance of peat added bricks.

Finally, the use of peat added bricks as an alternative walling material are likely to increase in the future. To make peat added bricks as alternative and lightweight building materials, the thermal insulation and adequate erosion resistance needs to be improved further for particular regions.

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APPENDICES

Appendix A: Engineering properties of peat added bricks

Table A1: Experimental values of the physical properties of brick samples

Sample	Unit weight (g/cm^3)	Absorption (%mass)	Porosity (%)	UPV value (Km/h)
Control mix	2.15±0.05	3.32±0.27	7.12±0.48	4.10±0.13
R-5	1.94±0.15	5.94±0.86	11.42±0.87	3.41±0.04
R-10	1.67±0.01	10.88±0.63	18.21±1.17	2.03±0.05
R-15	1.52±0.05	14.23±0.38	21.64±0.83	1.50±0.02
R-20	1.43±0.02	19.04±1.27	27.27±2.13	1.47±0.11
R-25	1.23±0.03	28.36±1.47	34.83±0.79	1.09±0.01

Table A2: Experimental values of the mechanical properties of brick samples

Sample	Compressive strength (Mpa)(28 days)	Flexural strength (MPa)	Splitting strength (MPa)
Control mix	31.70±3.62	2.69±0.20	3.35±0.01
R-5	16.40±0.43	2.04±0.18	0.85±0.03
R-10	9.08±0.75	0.92±0.03	0.48±0.01
R-15	3.82±0.03	0.68±0.04	0.41±0.01
R-20	3.37±0.87	0.58±0.05	0.32±0.02
R-25	2.80±0.11	0.33±0.04	0.19±0.04

Appendix B: Thermal Insulation performance of peat added bricks

Table B1: Time-Temperature values of the brick samples during the experiment

Time (minute)	Brick with 0% Peat	Brick with 10% Peat	Brick with 15% Peat	Brick with 20% Peat
0	62.2	62.3	62.3	62.2
15	61.9	62.1	62.1	61.8
30	61.4	61.9	61.8	61.5
45	61.1	61.7	61.4	61
60	60.9	61.5	61	60.7
75	60.5	61.3	60.6	60.3
90	60.1	60.9	60.2	59.9
105	59.7	60.5	59.6	59.3
120	59.2	60.1	59.2	58.8
135	58.7	59.8	58.7	58.3
150	58.2	59.4	58.2	57.9
165	57.8	59	57.8	57.3
180	57.3	58.7	57.4	56.9
195	57	58.3	57	56.4

Table B1: continue

Time (minute)	Brick with 0% Peat	Brick with 10% Peat	Brick with 15% Peat	Brick with 20% Peat
210	56.5	57.9	56.6	55.9
225	56.1	57.5	56.2	55.5
240	55.7	57.1	55.9	54.9
255	55.3	56.8	55.5	54.5
270	54.9	56.5	55.1	54.1
285	54.6	56.1	54.7	53.7
300	54.3	55.8	54.3	53.3
315	53.9	55.5	54	52.9
330	53.5	55.3	53.6	52.5
345	53.1	55	53.2	52.1
360	52.7	54.8	52.8	51.8
375	52.3	54.4	52.5	51.3
390	51.9	54.1	52.2	51

Table B1: continue

Time (minute)	Brick with 0% Peat	Brick with 10% Peat	Brick with 15% Peat	Brick with 20% Peat
390	51.9	54.1	52.2	51
405	51.6	53.8	51.9	50.6
420	51.2	53.2	51.6	50.3
435	50.9	52.8	51.3	50.1
450	50.6	52.6	51	49.8
465	50.3	52.3	50.7	49.4
480	50	52	50.4	49.2
495	49.7	51.7	50	48.9
510	49.4	51.6	49.7	48.6
525	49.1	51.5	49.5	48.3
540	48.9	51.2	49.2	47.9
555	48.6	51.1	49	47.6
570	48.3	50.8	48.8	47.2

Table B1: continue

Time (minute)	Brick with 0% Peat	Brick with 10% Peat	Brick with 15% Peat	Brick with 20% Peat
585	48	50.5	48.5	46.9
600	47.7	50.2	48.2	46.6
615	47.4	49.8	48	46.3
630	47.1	49.6	47.7	46
645	46.8	49.3	47.5	45.7
660	46.5	49.1	47.3	45.4
675	46.3	48.9	47.1	45
690	46.1	48.7	46.9	44.8
705	45.8	48.4	46.6	44.5
720	45.5	48.2	46.3	44.2
735	45.2	47.9	46.1	43.9
750	44.9	47.8	45.9	43.6
765	44.6	47.4	45.7	43.2

Table B1: continue

Time (minute)	Brick with 0% Peat	Brick with 10% Peat	Brick with 15% Peat	Brick with 20% Peat
780	44.3	47.1	45.4	42.9
795	44.1	46.9	45.1	42.7
810	43.9	46.6	44.9	42.4
825	43.6	46.4	44.6	42.1
840	43.4	46.1	44.3	41.9
855	43.2	46	44	41.6
870	43	45.7	43.7	41.3
885	42.7	45.5	43.4	41.1
900	42.5	45.2	43.2	40.9
915	42.2	45	43	40.7
930	42	44.7	42.8	40.5
945	41.8	44.4	42.6	40.3
960	41.6	44.2	42.4	40.1
975	41.4	44	42.2	39.9

Table B1: continue

Time (minute)	Brick with 0% Peat	Brick with 10% Peat	Brick with 15% Peat	Brick with 20% Peat
990	41.2	43.8	42	39.7
1005	41	43.6	41.8	39.5
1020	40.8	43.4	41.6	39.2
1035	40.6	43.1	41.4	39.1
1050	40.4	42.9	41.1	39
1065	40.2	42.6	40.9	38.8
1080	40	42.3	40.7	38.6
1095	39.8	42.1	40.5	38.3
1110	39.6	41.9	40.3	38.2
1125	39.4	41.7	40.1	38
1140	39.2	41.5	39.9	37.8
1155	39	41.3	39.7	37.6
1170	38.8	41.1	39.5	37.6
1185	38.6	40.9	39.3	37.4
1200	38.4	40.7	39.1	37.2

Appendix C: Photographs taken during experimental period

(a) (b) (c)

(d) (e) (f)

Figure C: (a) Liquid Limit, Plastic Limit test; (b) UPV test; (c) Compressive strength test; (d) Flexural strength test; (e) Erodibility test; (f) Thermal performance test.