STUDY ON MECHANICAL AND THERMAL PROPERTIES OF FIRED CLAY BRICK FROM FIVE DIFFERENT STATES IN MALAYSIA

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STUDY ON MECHANICAL AND THERMAL PROPERTIES OF FIRED CLAY BRICK FROM FIVE DIFFERENT STATES IN MALAYSIA

By

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Kajian ini bertujuan mengkaji sifat-sifat mekanik dan termal dari bata tanah liat yang diperolehi daripada lima negeri di Malaysia. Sifat mekanikal ditentukan dengan menggunakan ujian mekanikal. Bagi menyediakan asas untuk mengenal pasti tingkah laku bahan-bahan di bawah keadaan beban yang berbeza dan bentuk komponen dari mereka. Ciri termal ialah sifat-sifat bahan yang berkaitan dengan kekonduksian habanya. Kualiti bata tanah liat yang diperolehi daripada kilang yang berlainan mempunyai kaedah yang berbeza dalam proses pembuatannya. Ini adalah salah satu faktor utama bagi masalah ini, bagi mengetahui penghasilan batu bata tanah liat yang dihasilkan dengan baik dan bagaimana untuk meningkatkan kualiti bata tanah liat yang telah sedia ada. Selain itu, suhu sering menjadi faktor yang penting untuk mengekalkan keselesaan termal dalaman yang optimum apabila kelembapan disimpan sekitar 50% dengan tiada pergerakan udara. Ujikaji yang dijalankan termasuklah ujian penyerapan air, ujian kekuatan mampatan, ujian lenturan, ujian termal, ujian ketumpatan dan ujian tanpa musnah (UPV) dari bata tanah liat yang diperolehi daripada lima negeri yang berlainan. Berdasarkan keputusan yang diperoleh, bata tanah liat daripada Rantau Panjang, Kelantan menunjukkan kekuatan mampatan tertinggi daripada batu bata tanah liat daripada negeri lain. Selain itu, ia mempunyai kekuatan lenturan yang lebih tinggi, dan penyerapan air yang lebih rendah yang cenderung menghasilkan kualiti bata yang baik. Lebih-lebih lagi, nilai ujian tanpa musnah UPV lebih tinggi daripada batu bata yang lain. Kekuatan mampatan dan lenturan bata yang lebih tinggi terdiri daripada penyerapan air yang rendah disebabkan oleh kekurangan keliangan udara. Akibatnya, kekonduksian termal berkurangan dengan penurunan ketumpatan dan peningkatan dalam keliangan udara bata tanah liat. Kesimpulannya, kualiti batu bata terbaik dari lima negeri di Malaysia adalah batu bata dari Rantau Panjang, Kelantan.

ABSTRACT

This research was to study the mechanical and thermal properties of fired clay brick from five different states in Malaysia. Mechanical properties are determined by the behaviour under applied forces using mechanical test. Thus, provides the basic for predicting behaviour of materials under different load condition and designing the components out of them. Thermal properties are those properties of a material which is related to its conductivity of heat. The quality of fired clay brick from different factory varies due to the different method of a manufacturing process. This is one of the main contributing factors for the problem which is to identify the best manufactured fired clay brick and how to improve the quality of the existing fired clay brick produced. Besides, the temperature often becoming the most important factor to maintain the optimum indoor thermal comfort when the humidity is kept at around 50% with absent of air movement. The experiment were conducted including water absorption test, compressive strength test, flexural test, thermal test, density test and non-destructive test Ultrasonic Pulse Velocity (UPV) of the fired clay brick from five different states. Based on the result obtained, the fired clay brick from Rantau Panjang, Kelantan shows the highest compressive strength than other fired clay brick. Besides, it has the higher flexural strength, and lower water absorption which tend to produce the good quality of brick. Moreover, the value of the hardness tests which Ultrasonic Pulse Velocity (UPV) was higher than other brick. The higher compressive strength and flexural of brick consists of low water absorption due to less porosity. As a result, the thermal conductivity decreases with decrease in density and increase in fired clay bricks porosity. As conclusion, the best quality of brick from five different states in Malaysia was brick from Rantau Panjang, Kelantan.

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LIST OF ABBREVIATIONS

ASTM	**A**merican **S**ociety for **T**esting and **M**aterial
BS	**B**ritish **S**tandard
ISO	**I**nternational **O**rganization of **S**tandardization
BC	**B**efore **C**hrist
TPS	**T**ransient **P**lane **S**ource
UPV	**U**ltrasonic **P**ulse **V**elocity

NOMENCLATURES

k	Thermal Conductivity
c	Specific Heat
ρ	Density
Q	The heat added
c	Specific heat
m	Mass
ΔT	Change in temperature
q	The rate of conduction heat transfer
A	Area perpendicular to heat flow/ Surface Area
L	Distance through which conduction heat transfer is taking place
W_{dry}	Weight after cube sample dried in oven
W_{wet}	Weight after immersed sample in tank
m_1	Mass of wet brick
m_2	Submerged mass of brick
m_o	Ambient mass (g)
P	Porosity (%)
W_{air}	Weight at the saturation wet in the air (g)
W_{sat}	Weight in water (g)
fm	Compressive Strength
P	Maximum Load (Compression Strength)
W	Maximum load (N)
l	Distance Between Supporting Roller (mm)

b	Net width(mm)
d	Depth(mm)
x	Average distances from midspan(mm)
V	Pulse Velocity
L	Length(UPV)
T	Effective Time

CHAPTER 1

INTRODUCTION

1.1 Background

Clay bricks are indeed amongst the most commonly used materials in the construction materials and known for its engineering properties. The engineering properties of clay brick masonry rely mostly on the features of the brick units, which depend on the quality of the raw materials used and the manufacturing process. The manufacturing process plays important roles in the quality control by permits the manufacturer to limit the variations of the uniform product. Francisco et al., 2009, stated that the properties of the raw materials used in the manufacturing process are crucial to obtain the desired engineering properties such as the physical, chemical and mechanical properties.

The thermal properties of clay brick is important in engineering which influence how the heat energy is passing through the brick. Heat is a form of energy and considered as a transfer process from one sources to another location through a conductor as a result of a temperature difference between its two ends. Some materials have the ability to store a large quantity of heat while others are in small quantity. The final pore volume fraction depends on its thermal conductivity. This is the nature of raw materials during solid phase transformation cause by thermal treatment (James .et al, 2016).

As a whole, the brick is important in construction and to make sure that the right products are selected for a certain project. Knowledge of the mechanical and thermal properties of brick is essential as guidelines for civil engineering. The study has been carried out using samples from five different fired clay brick factories in

Malaysia to observe its mechanical and thermal properties. The selection of fired clay brick in this research based on shape, size and colours which were free from crack, square shape and sharply define edges. Besides, the dimensional accuracy of each brick were consistent.

1.2 Problem Statement

Brick is one of the most adaptable materials units due to its properties. The fired clay brick manufacture in Malaysia produced its own type of fired clay bricks to be used for construction. Therefore, the quality of fired clay brick from different factory varies due to the different method of a manufacturing process. This is one of the main contributing factors for the problem which is to identify the best manufactured fired clay brick and how to improve the quality of the existing fired clay brick produced. The data obtain such as compressive strength, water absorption, flexural strength and ultrasonic pulse velocity of fired clay bricks from this study can be useful information to the brick user in Malaysia.

The study on the properties of fired clay brick is important because the thermal process describes a material's ability to absorb and store heat. Fired clay brick in a building with high thermal mass will react slowly to the temperature cause by solar radiation, by absorbing its. Therefore, it reducing the energy usage in the building (Brick Industry Association, 2016). The temperature often becoming the most important factor to maintain the optimum indoor thermal comfort when the humidity is kept at around 50% with absent of air movement. It is very hard to maintain constant and optimum thermal conditions in the offices as human beings are actually very sensitive to the thermal changes (Othuman Mydin et al, 2017).

1.3 Objectives

The objectives of the research are:

1. To determine the mechanical properties of fired clay bricks from five different states.
2. To determine the thermal properties of fired clay bricks from five different states.

1.4 Benefit of Research

The potential benefits of proposed research project will help the brick industrial to have new type of masonry unit data on various types of fired clay brick. Thus, able to correlate quality of fired clay brick unit to the process of manufacturing and material sources.

1.5 Scope of Work

The research is dealt with the investigation of fired clay bricks from five different states which are from Kelantan, Selangor, Kedah, Perak and Penang. The bricks were tested under laboratory conditions as specified by the respective standards. The clay brick properties examined were confined to studies on compressive strength, water absorption, flexural strength, ultrasonic pulse velocity and thermal conductivity. The standards used in the study were American society for testing and material (ASTM), British Standard, BS 3921:1969 and International Organization of Standardization (ISO).

1.6 Dissertation Online

The research consists of five chapters which are introduction, literature review, methodology, result and discussion and conclusion. This section describes the general outline of this thesis and explanation for each chapter.

Chapter one introduces the overall background of this research, followed by problem statement to identify and understand the reasons to carry out this research. Then, it was followed by the objectives in order to set the desired target to be achieved.

Then, in the second chapter, a literature review on the research title, fired clay brick, mechanical and thermal properties. Previous studies of engineering properties of clay brick will be further discussed in this chapter.

The chapter three will focus on the methodology of this research. In this chapter, the methods, tests conducted, and standard references will be presented in detail to enhance the understanding of the execution of this research. Methods of specimen preparation, purposes of tests carried out and its relevance to this research will be justified.

Next, chapter four presented the results and discussion of this research to ensure that the objectives have been achieved and produced substantial results to improve the future studies or to be used in real projects. Results from the specimens testing will be provided and justified.

Finally, in chapter five, the overall research will be concluded and a brief summary of the outcomes will be written and recommendations for further research in the future will be discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, the literature will be reviewed and summarily presented. This chapter will cover the contents and background about fired clay brick, history, manufacture and its engineering properties. This chapter also covers the related past investigations on mechanical and thermal properties of fired clay brick.

2.2 Fired Clay Brick

The fired clay brick in Figure 2.1 is used as partition wall in building construction and also the main component of construction. Fired-clay bricks are made by forming the unit from moist clay by pressing, extrusion or hand throwing technique followed by drying and firing to a temperature usually in the range of 850-1300º C. During the firing process, complex chemical changes occur and clay particles are bonded together by heating or sintering process. Most important properties of fired-clay bricks are fire resistance. A good fired-clay brick can withstand heat more than 1000ºC.

Figure 2.1: Fired Clay Brick (Brick Construction Material, 2015)

2.3 History of Fired Clay Brick

For many years, bricks were hand-moulded and sun-dried giving them rather fragile properties, but around 2500 BC the first fired bricks are produced. Since 3000 BC, as humans started to settle, bricks appeared as an interesting product, resistant, easily workable and usable, meaning that people could effectively protect themselves against the elements such as rain or wind and predators (Chabat, cited in Hisham, 2016).

In Mesopotamia the first masonry units were based on dried mud and were used for the first time around 8000 BC, an area bordered by the Tigris and Euphrates rivers stretching from Southeast Turkey, Northern Syria, and Iraq reaching the Arabic Gulf (Pacheco-Torgal, & Jalali, cited in Hisham, 2016).

The early forms of masonry application in Malaysia dated back about 350 years ago with the construction of the Stadthuys in Malacca, built by the Dutch in 1650. A more modern form of masonry construction was initiated by the British who colonized the then Malayan Peninsula. Brickwork buildings were at that time built specially for government offices, quarters and residential. The administrative block, Sultan Abdul Samad building built in 1894 and given a face-lift during the Fourth Malaysian Plan (1981 – 1985) is an example of a masonry heritage, which stands as a remarkable landmark of Kuala Lumpur in Figure 2.2 (Zainab, 2005).

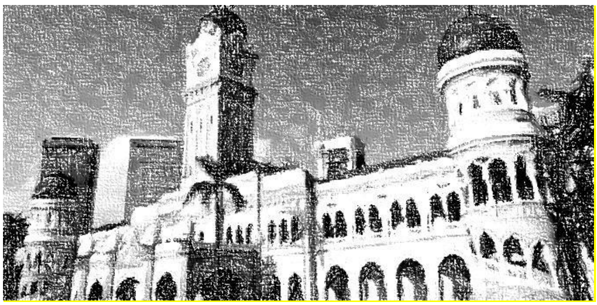

Figure 2.2: Sultan Abdul Samad Historical Building (Visit Malaysia, 2012)

2.4 The manufacture of Fired Clay Brick

The manufacture of brick and structural clay products involves mining, grinding, screening and blending of the raw materials followed by forming, cutting or shaping, drying, firing, cooling, storage, and shipping of the final product. A typical brick manufacturing process is shown in Figure 2.3.

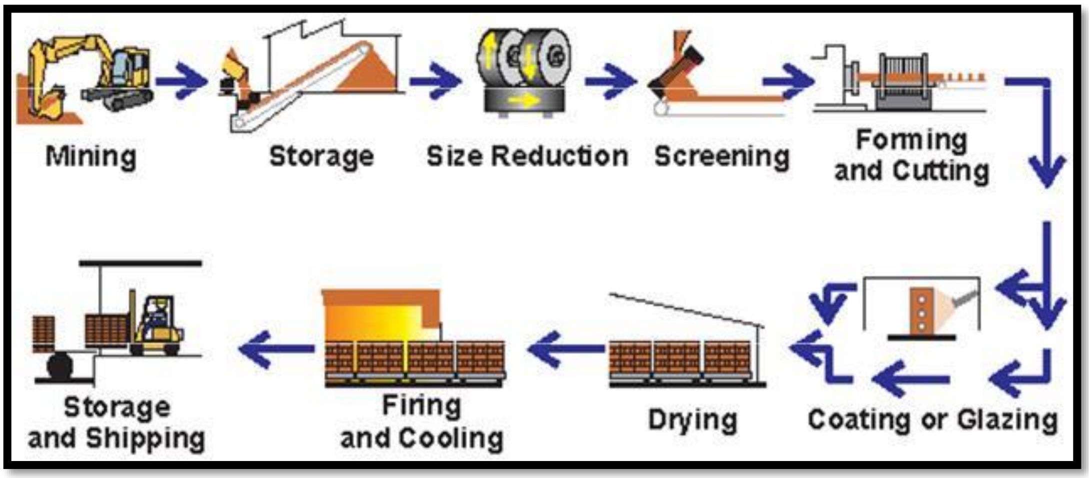

Figure 2.3: The manufacturing process of fired clay brick (Brick Industry Association, 2016)

2.4.1 Mining, prepare the storage of raw material.

Surface clays, shales, and some fire clays are mined in open pits with power equipment. Then the clay or shale mixtures are raw materials that transported to plant storage areas are prepared to produce the fired clay brick product. The material has to be in small particles using the size-reduction machines to break up large clay lumps and stones before mixing the raw material. Usually, the material is processed through inclined vibrating screens to control particle size. The main body of brick is made by using natural clay minerals, kaolin and shale and small amounts of manganese, barium, and other additives are blended with the clay to produce different shades, and barium carbonate is used to improve brick's chemical resistance to the elements (Brick Industry Association, 2016).

2.4.2 Forming the brick using a common method.

The extrusion process is the most common method of brick forming and pulverized material. Before the extrusion process, the water are fed into one end of a pug mill, which uses knives on a rotating shaft to cut through and fold together material in a shallow chamber as in Figure 2.4. The blend is then filled into an extruder at the far end of the mill (Jones and Berard, 1972). After it is compressed, the plastic material is forced out of the chamber through a specially shaped die orifice as in Figure 2.5. Sections of the desired length are cut to size with rotating knives or stiff wires. The interior of the box is often coated with sand, which provides the desired texture and facilitates removing the formed brick from the mould. The material is placed in a die and then compacted with a steel plunger set at the desired pressure. The sand coating, also applied as the brick is extruded, depends on how soft or hard the extruded material is (How Product are Made, 2009).

Figure 2.4: Clay mixed with water in pug mill before extrusion (Brick Industry Association, 2016)

Figure 2.5: Clay is extruded through a die and trimmed to specified dimension before firing (Brick Industry Association, 2016)

2.4.3 Drying and kilns process.

Before the brick is fired, it must be dried to remove excess moisture. If this moisture is not removed, the water will burn off too quickly during firing, causing cracking. These racks are then transferred by rail-mounted transfer cars or by lift trucks into the dryers. After drying, the brick is loaded onto cars and fired to high temperatures in furnaces called kilns as in Figure 2.6. These cars are pushed through the kiln's continuously maintained temperature zones at a specific rate that depends on the material (How Product are Made, 2009).

Figure 2.6: Brick Enter Tunnel Kiln for Firing (Brick Industry Association, 2016)

2.4.4 Storage and shipping of the brick.

After the brick is fired and cooled, it is unloaded from the kiln car via the hacking process, which has been automated to the point where almost all manual brick handling is eliminated. Automated setting machines have been developed that can set brick at rates of over 18,000 per hour and can rotate the brick 180 degrees. Usually set in rows eleven bricks wide, a stack is wrapped with steel bands and fitted with plastic strips that serve as corner protectors. The packaged brick is then shipped to the job site, where it is typically unloaded using boom trucks (How Product are Made, 2009).

2.5 Classification of brick

2.5.1 Common Brick

Common brick shows in Figure 2.7 is a general multi-purpose unit manufactured economically without special reference to appearance. These may vary greatly in strength and durability and are used for filling, backing and in walls where appearance is of no consequence. It tends to have lower compressive strengths than facing bricks or engineering bricks and generally lower quality.

Figure 2.7: Common Brick (Golden Brick, 2006)

2.5.2 Facing Brick

Facing brick are made primarily with a view to having good appearance, either of colour or texture or both as shown in Figure 2.8. These are durable under severe exposure and primarily used for the external walls of a building and so are generally chosen for their aesthetic qualities.

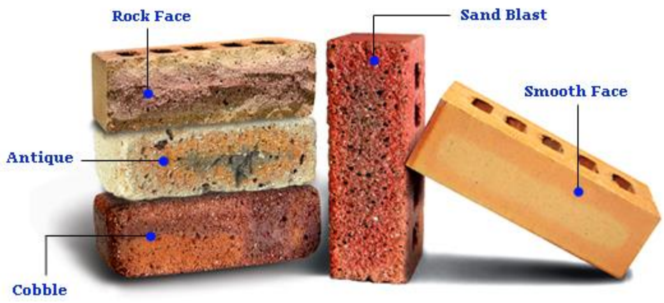

Figure 2.8: Facing Brick (Wong, 2012)

2.5.3 Engineering Brick

Engineering Brick shows in Figure 2.9 are strong, impermeable, smooth, table moulded, hard and conform to defined limits of absorption and strength. It has a high compressive strength and low water absorption. They were traditionally used in civil engineering and are most suitable for applications where strength and resistance to frost attack and water are important which are used for all load-bearing structures.

Figure 2.9: Engineering Brick (Wienerberger, 2018)

2.6 Characteristic of Brick

For a good structure, bricks should be good and well burnt. In a construction site, sometimes its need to check if the bricks are of good quality or it is not. Authorities should be able to identify good bricks without any extra instrument. Thus, it was important to know the characteristics of bricks (Duggal, 2008).

The characteristic of brick are as below:

a) **Size and Shape** of bricks should have uniform size and plane, rectangular surfaces with parallel sides and sharp straight edges.
b) **Colour** of brick should have a uniform deep red or cherry colour as indicative of uniformity in chemical composition and thoroughness in the burning of the brick.
c) **Texture and Compactness** of surfaces should not be too smooth to cause slipping of mortar and should have pre-compact and uniform texture. A fractured surface should not show fissures, holes grits or lumps of lime.
d) **Hardness and Soundness** of brick should be so hard that when scratched by a finger nail no impression is made. When two bricks are struck together, a metallic sound should be produced.
e) **Water Absorption** should not exceed 20 per cent of its dry weight when kept immersed in water for 24 hours.
f) **Compressive Strength** should not be less than 10 N/mm^2.
g) **Brick Earth** should be free from stones, lime concentration, organic matter, potassium nitrate, etc.

2.7 Mechanical properties

The mechanical properties of a material describe how it will react to physical forces. Mechanical properties occur as a result of the physical properties inherent to each material and are determined through a series of standardized mechanical tests. The mechanical properties of bricks are frequently reported in the literature, so it is possible to gather a large amount of data. The mechanical properties include the compressive strength, flexural strength, hardness and water absorption.

2.7.1 Water absorption

Water absorption can be determined by soaking the brick in the water by observe the amount of water that can absorb as air in the pores fill the holes in the brick may prevent total absorption and to find total absorption the bricks have to be boiled in water or heated. Then, data is collected by observe the amount of water absorbed and the rate of absorption under specified conditions. The amount of the water in a brick will absorb is a guide to its density and therefore its strength in resisting crushing. The factors affecting water absorption include the type of plastic, additives used, temperature and length of exposure (Civil Construction Tips, 2011).

According to Francisco et al., 2009 the water absorption occurs when the pores constitute a large part of the brick's volume, and when the brick are exposed to rainfall or rising damp, water generally penetrates into the pores. Water absorption then determines the capacity of the fluid to be stored and to circulate within the brick, favouring deterioration and reduction of mechanical strength.

Based on BS 3921 (1985) standard for clay bricks classified the bricks by their water absorption as shown in Table 2.1. The standard stated that the low water absorption <4.5% to classify engineering class A bricks and bricks for damp proof courses 1, and higher water absorption <7.0% to classify engineering class B bricks and bricks for damp proof courses 2. There are no limits on water absorption for all other types of clay bricks. Water absorption, like strength, is not a general index of durability; but with many clay bricks, the bricks that absorb less water may be considered to be more durable than the ones with high water absorption (Khalaf and DeVenny, 2002).

Table 2.1: Water Absorption based on BS3921 (1985)

Class	Water Absorption (%)
Engineering A	$\leq$ 4.5%
Engineering B	$\leq$ 7.0%
Damp-proof course 1	$\leq$ 4.5%
Damp-proof course 2	$\leq$ 7.0%

2.7.2 Compressive Strength

This is a property of bricks which can be determined accurately. The compressive strength of bricks is found by crushing of them individually until they fail or crumble. The pressure required to crush them is noted and the average compressive strength of the brick is stated as newton per mm of surface area required to ultimately crush the brick. The crushing resistance varies from about 3.5 N/mm² for soft facing bricks up to 140 N/mm² for engineering bricks (Civil Construction Tips, 2011).

The strength of a single brick masonry unit varies widely, depending on its ingredients and manufacturing method. Brick can have an ultimate compressive strength as low as 11.03 MPa. On the other hand, some well-burned brick has compressive strength exceeding 103.42 MPa (Integrated Publishing Jones, 2013).

Based on BS 3921 (1985) standard for clay bricks classified the bricks by their compressive strength as shown in Table 2.2. The standard stated that the low compressive strength ≥ 50 N/mm^2 to classify engineering class A bricks and bricks for damp proof courses 1, and higher compressive strength ≥ 70 N/mm^2 to classify engineering class B bricks. Besides, for the damp courses 1 (use in walls in habitable buildings) and damp courses 2 (use in garden walls, etc.) have same value which ≥ 5 N/mm^2.

Table 2.2: Compressive Strength based on BS3921 (1985)

Class	Compressive Strength (N/mm^2)
Engineering A	≥ 70
Engineering B	≥ 50
Damp-proof course 1	≥ 5
Damp-proof course 2	≥ 5

Based on BS 3921 (1985) Crushing or compressive strength varies widely, a clay common may have a strength as low as 4 N/mm^2 whereas an engineering brick may be as high as 180 N/mm^2.

Compressive strength is strongly influenced by the characteristics of the raw material and by the production process. It is known that the raw clay of old bricks were often of low quality and the manufacturing process was relatively primitive and inefficient. Other characteristics of existing old bricks can provide an indication about compressive strength, such as mineral composition, texture, crack pattern and porosity level, by revealing the conditions of drying and firing (Francisco et al., 2009).

2.7.3 Non-destructive test (Ultrasonic Pulse Velocity)

One of these is the measurement of ultrasound pulse velocity (UPV) which provides important information about the internal structure of materials. With this technique, relationships between internal structure and mechanical properties of numerous materials can be studied (Kurugol, 2012). UPV is commonly used to predict and evaluate the mechanical properties of various materials in a non-destructive way. Vasconcelos,2008 stated that many studies were made on the relationships between UPV and strength and, elastic properties of natural and artificial stones, especially those of cement-binder concrete and mortars as well as wood materials.

2.8 Thermal properties

Thermal properties are those properties of a material which is related to its conductivity of heat. In other words, these are the properties which are exhibited by a material when heat is passed through it and a material decides how it reacts when it is subjected to heat fluctuation. The thermal properties include the specific heat, thermal conductivity and diffusivity.

2.8.1 Thermal conductivity

Thermal conductivity is the amount of heat per unit time and unit area that can be conducted through a plate of unit thickness. Thermal conduction is ability to the transfer of heat from one part of a body to another with which it is in contact. Thermal conductivity λ is defined as ability of material to transmit heat and it is measured in watts per square metre of surface area for a temperature gradient of 1 k per unit thickness of 1 m (Keith Mobley, 2001).

The main factors affected the thermal conductivity are the density of material, moisture of material and ambient temperature. With increasing density, moisture and temperature the thermal conductivity increases too. Most material achieves their insulating properties by virtue the high void content of their structure. The void inhibits convective heat transfer because of their small size. Reduction in void size, reduce convection but increase the volume of material. The temperature affected by the increasing the thermal conductivity along with the temperature. The insulating medium such as gas or air within the voids becomes more excited as its temperature is raised, and this enhances convection between the voids, and then increased the heat flow. Thus, this increase in thermal conductivity is generally continuous for air-filled product (Keith Mobley, 2001).

The important is the inner structure of materials, metals and other dense solid materials tend to have high levels of conductivity, whereas materials with very small amount of solid matter and large proportion or voids have the lowest thermal conductivities. Thermal conductivity of some building materials is given in Table 2.3.

Table 2.3: Thermal conductivity of selected building materials (at about 20° C) (Building Material 10, 2012)

Material	Thermal Conductivity (W/mK)
Mineral or glass wool	0.04-0.08
Lightweight concrete	0.11-0.25
Timber (Pine)	0.14
Water	0.60
Brick	0.65-0.80
Glass	0.6-1.38
Concrete	1.2-1.75

2.8.2 Thermal diffusivity

Thermal diffusivity is the thermal conductivity divided by the volumetric heat capacity and also called as heat conductivity or thermometric conductivity. The ratio of the thermal conductivity k of a substance to the product of its specific heat c and its density ρ as Equation 2.1:

$$K = k/cp \qquad \text{………. Equation 2.1}$$

For a gas, c is the specific heat at constant pressure, c_p. The thermal diffusivity determines the rate of heating given the temperature distribution according to an equation, which for one spatial dimension as Equation 2.2:

$$\frac{dT}{dt} = K\,\frac{d^2T}{dz^2} \qquad \text{………. Equation 2.2}$$

At a temperature of 0°C, the thermal diffusivity for air is 1.9 x 10^{-5} m^2 s^{-1}. At other temperatures, the ratio μ/K is nearly constant, where μ is the dynamic viscosity and diffusivity, kinematic viscosity (Robert, 1951). The thermal diffusivity of selected building materials was shown as Table 2.4.

Table 2.4: Thermal diffusivity of selected building materials **(**Engineer Edge, 2018)

Material	Thermal diffusivity (m^2/s)	Thermal diffusivity (mm^2/s)
Helium (300K, 1 atm)	1.90×10^{-4}	190
Hydrogen (300K, 1 atm)	1.60×10^{-4}	160
Nitrogen (300K, 1 atm)	2.20×10^{-5}	22
Pyrolytic graphite, normal to layers	3.60×10^{-6}	3.6
Tin	5.2×10^{-7}	0.52
Brick, common	2.7×10^{-7}	0.27
Brick, adobe	3.4×10^{-7}	0.34

2.8.3 Specific heat

Specific heat is the heat required to raise the temperature of the unit mass of a given substance by a given amount usually one degree (Nave, 2017). The temperature of matter is a direct measure of the motion of the molecules as the greater the motion the higher the temperature produce. Motion energy is stated that, the more energy matter has the higher temperature is supplied by heat. Heat loss or gain by matter is equivalent energy loss or gain as shown in Figure 2.10 (De Leon, 2001)

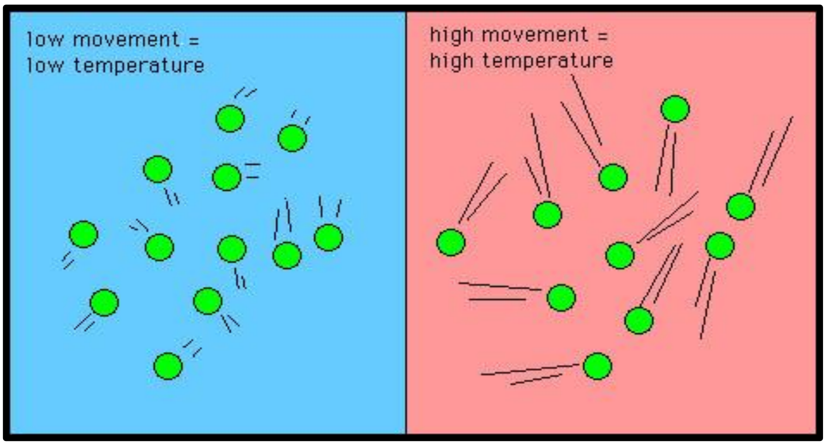

Figure 2.10: The motion of molecule (De Leon, 2001)

The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius as Equation 2.3. The relationship between heat and temperature change is usually expressed in the form shown below where c is the specific heat. The relationship does not apply if a phase change is encountered, because the heat added or removed during a phase change does not change the temperature.

$$Q = cm\Delta T \qquad \text{………. Equation 2.3}$$

Where,

Q = the heat added

c = specific heat

m = mass

ΔT = change in the temperature

The specific heat of water is 1 calorie/gram °C = 4.186 joule/gram °C which is higher than any other common substance. As a result, water plays a very important role in temperature regulation (Nave, 2017). The specific heats of selected building materials were shown as Table 2.5.

Table 2.5 : Specific heat of selected building materials (Paul, 2016)

Material	J/kg.K	MJ/kg.K
Aluminium	887	0.887
Asphalt	915	0.915
Brick	841	0.841
Cast Iron	554	0.554
Clay	878	0.878
Brass	920	0.920
Boron	1106	1.106

The transient plane source (TPS) thermal characterization technique as shown Figure 2.11 is becoming an important tool for the determination of the thermal properties of a variety of materials due to its robust design, rapid characterization time and for its ability to simultaneously measure the thermal conductivity and thermal diffusivity of complex materials (Warzoha and Fleischer, 2014). The thermal conductivity which is defines as the property of a material to conduct heat. More precisely, it is the amount of heat per unit time and unit area that can be conducted through a plate of unit thickness. (Al-Ajlan, 2006).

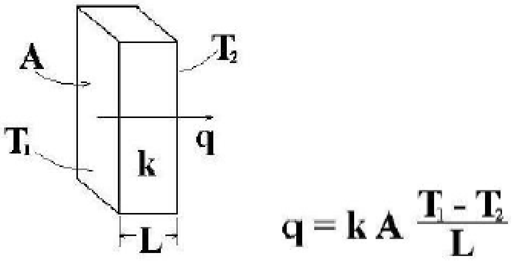

Figure 2.11: Thermal conductivity TPS (Warzoha and Fleischer, 2014)

Where,

q = the rate of conduction heat transfer

k = thermal conductivity of the material

A = area perpendicular to heat flow

ΔT = the temperature and

L = the distance through which conduction heat transfer is taking place

Table 2.6: Specifications of the device (Hotdiskinstruments.com, 2014)

Thermal Conductivity	0.005 to 1800 W/m/K.
Thermal Diffusivity	0.1 to 1200 mm^2/s.
Specific Heat Capacity	Up to 5 MJ/m^3K.
Measurement Time	1 to 1280 seconds.
Reproducibility	Typically better than 1 %.
Accuracy	Better than 5 %.
Temperature Range	-253 °C to 1000 °C.
With Furnace	Ambient to 750 °C [1000 °C oxygen free].
With Circulator	-35 °C to 200 °C.
Smallest Sample Dimensions	0.5 mm × 2 mm diameter or square for bulk testing. 0.1 mm × 10 mm diameter or square for slab testing. 10 mm × 5 mm diameter or square for one-dimensional testing.
Sensor Types Available	All Kapton sensors. All Mica sensors. All Teflon sensors

Table 2.7: Result of Fibrous materials (Gur'ev et al., 1999)

Sample ID	The Conductivity (W/(m. K)).	The Diffusivity (m^2/s)	Specific Heat (J/(kg·K))
Steel standard	13.53988355	3.90131075	3.470598579
LLDPE	0.379188712	0.231995114	1.634468523
Sample-A	0.965682173	0.203704327	4.74060708
Sample-B	3.099836426	1.40954279	2.199178661

Concerning thermal properties, the majority focused mainly on the effect of varying operating temperature, giving only some hints about moisture content. A research performed by (Gur'ev et al., 1999) on fibrous materials showed that the moisture content influences considerably their thermal conductivity. Based on the result from the Table 2.7 by comparing their results with those already present in the literature, they observed that a 1% increase in volume of the water content in a fibrous structure with density up to 150 kg/m^3 results in an increase of the thermal conductivity equal to 8%.

2.9 Previous Research of Clay Brick

Clay bricks exhibit a set of properties that are important in the evaluation of strength and durability. The properties are closely related to the quality of the raw clay and directly associated with the conditions of manufacture. This research is to study the mechanical and thermal properties of fire clay brick in five different states. The testing method also stated in other table to know each testing was conducted in the experiment of previous studies shows in Table 2.8 and Table 2.9.

Table 2.8: Previous works reported by other authors

No	Author	Title	Description
1	Francesco D'Alessandro, Giorgio Baldinelli , Francesco Bianchi, Sara Sambuco, Alessandra Rufini (2018)	Experimental assessment of the water content influence on thermo-acoustic performance of building insulation materials	-This study is to determine the link between thermo-acoustic performance, in terms of thermal conductivity and absorption coefficient, and water content of selected building insulation materials. -Although thermal conductivity increases with water content for each of the analysed materials, except for mineral wool, trends are different. -Polyurethane foam able to absorb small quantities of water, but k changes significantly, 17% increase for a variation of water content lower than 3%. -On the contrary, kenaf and melamine foam experience higher modifications of k (+41% and +46% respectively) but the variation of water content results definitely higher than the one occurring in polyurethane foam, i.e. 19% for kenaf and 25% for melamine foam.
2	Md. Roknuzzaman, Md. Belal Hossain, Md. Ibrahim Mostazid, Md. Rashedul Haque (2017)	Application of Rebound Hammer Method for Estimating Compressive Strength of Bricks	-This paper presents some models for correlation between rebound number and compressive strength of bricks. -10 different samples of brick were collected from different manufacturers and rebound numbers was taken 20 times for each brick, 10 times for horizontal hammer position and 10 times for vertical. -Rebound number was found to be high comparative to its low compressive

			strength. This was considered an experimental error and this sample was excluded in further calculations.
3	P. Munoz V., M.P. Morales O., V. Letelier G., M.A. Mendivil G. (2016)	Fired clay bricks made by adding wastes: Assessment of the impact on physical, mechanical and thermal properties	- Acceptable estimation of fired clay bricks properties, when wastes are added. -Summarizes raw materials characterization and methods of most cited papers. -Despite mechanical, physical and thermal properties highly depend on several parameters when residues are classified -Results are related to the relative variation of density, a good correlation, between different papers, is found.
4	Aruna Ukwatta, Abbas Mohajerani, Nicky Eshtiaghi, Sujeeva Setunge (2015)	Variation in physical and mechanical properties of fired clay bricks incorporating ETP bio solids	-Investigating the possibility of incorporating bio solids from Melbourne's Eastern Treatment Plant (ETP) in fired clay bricks. -The effect of incorporating ETP bio solids in a ceramic body on the physical and mechanical properties of fired-bricks. -The leachate analysis results showed that the concentration of heavy metals leached is insignificant and much lower than the regulatory limits.
5	N. Laaroussi, G. Lauriat, M. Garoum, A. Cherki, Y. Jannot (2014)	Measurement of thermal properties of brick materials based on clay mixtures	-The thermal properties of clay samples, coming from the Moroccan Slaoui’s factory, have been measured through the use of different methods. -The differential scanning calorimeters, entered hot plate in steady state or transient regimes and flash methods were applied to clay samples issued from a local manufacturer. -For the measurements of heat conductivity, diffusivity and volumetric capacity, the measurement techniques are essentially based on the measure of the steady or transient temperature at the center of a sample heated with a prescribed uniform flux. -The comparisons between the different measurement techniques showed fair accuracies.
6	Aeslina Abdul Kadir ,Abbas Mohajera. (2013)	Physical and Mechanical Properties of Fired Clay Bricks Incorporated	- In this study, two types of brick samples were used: the standard clay bricks and clay bricks incorporated with cigarette butts (CB). -To evaluate the effect of slow heating