CHAPTER 2

REVIEW OF THE LITERATURE

Bricks can be sun-dried or fired in a furnace at a temperature ranging from 900 – 1200 ^{o}C. However, fired bricks are usually stronger than sun-dried bricks, especially when they are made of clay. Clay suitable for brick making should contain the following ingredients by weight: silica 50%, alumina 20-30%, lime 2-5%, iron oxide 5-6% and magnesia less than 1%. In this study, we used Hang Dong clay which contains desirable ingredients for brick making and it is also local material in the northern region of Thailand. With the appropriate proportion of these ingredients, good qualities of clay bricks can be achieved, namely, color, shape, texture, size, strength, water absorption, thermal conductivity and fire resistance. However, certain additives added to clay can enhance better qualities in bricks. We selected charcoal as additive to be studied. The main qualities of fired test briquettes with charcoal addition we focus on in this study are thermal conductivity and compressive strength. Thus, the literature of mechanical and physical properties which are the internal structures of clay bricks, namely bulk density, water absorption and apparent porosity are reviewed, and reported.

Hang Dong (HD) Clays

HD Clay is suitable for brick making because it mainly consists of silica oxide (48.41%) and alumina oxide (24.01%) mixed in such a proportion as to enable it to be rendered in a plastic state when mixed with water. Silica reacts chemically with alumina forming silicate of alumina. It enables bricks to retain their shapes and make them durable. Excess of silica than 50% destroys cohesion and makes bricks brittle and weak. In addition, the percentage of alumina, 24.01% is appropriate as a basis constituent in good brick clay because excess of alumina of more than 30% makes the brick crack and warp on drying. In the plastic state, HD clay can be capable of being molded into any desired shape and the bricks so formed do not crack or warp on drying and burning. In addition to silica and alumina, HD clay contains other small proportions of lime (CaO) 0.29%, ferric oxide (Fe_2O_3) 6.25%, manganese oxide (MnO) 2.33%, and potassium (K_2O) 4.47%. Moreover, the major crystalline phase found in Hang Dong clay are quartz, muscovite, kaolinite, alkali-feldspar and hematite.

2.1 Clays

Clay suitable for brick making should mainly consist of silica and alumina mixed in such a proportion as to enable it to be rendered in a plastic state when mixed with water. In the plastic state the brick clay should be capable of being moulded into any desired shape and the bricks so formed should not crack or warp on drying and burning. In addition to silica and alumina, the brick clay should contain a small proportion of lime, iron, manganese, magnesium, sulphur, postassium and phosphates. The function of important ingredients of brick clay are given below.

Alumina is the basis constituent, which readily absorbs water and imparts plasticity to the clay. The percentage of alumina in good brick clay should vary between 20 to 30 percent. Excess of alumina in the clay makes the brick crack and warp on drying.

Silica reacts chemically with alumina forming silicate of alumina. Silica enable the brick to retain its shape and makes it durable. It prevents shrinkage, warping and undo hardness of the brick. Excess of silica destroys cohesion and makes the brick brittle and weak. The percentage of silica in good brick clay should vary between 35 to 50 percent.

Iron is an important subsidiary ingredient in the clay, which affects both the character and the color of the finished product. The color of the brick depends upon the extent an iron oxide present in the clay. The color of brick ranges from high yellow to orange and red and the color deepen with the proportionate increase in the iron oxide content. Iron also enhances the impermeability and durability of the brick.

Magnesia primarily affects the color of the brick.

Lime, if limestone is presented in clay the right proportion in a finely divided state will result in a sound brick. If excessive lime is presented, it becomes harmful and the color of bricks tends to change from red to yellow. If limestone is presented in the form of small lumps, it will remain as lumps in the finished brick. When such a brick comes on contact with water, or dampness, the lumps of lime will start slaking. During slaking, lime expands and this results in the cracking of the brick [17].

2.2 Manufacture of bricks

Brick is used in temples, buildings and houses and has an enormous range of used for the construction of roads, bridges, dams etc. Bricks have a major role as a construction material in most developing countries. Intensive labor and low investment costs are two main advantages in developing countries, which are attractive to builders and owners.

Bricks are formed or shaped by one of four processes:

- Extrusion and wire-cutting: A square-ended column of wet clay is squeezed through a die and then wire-cut. Usually these bricks are perforated to accelerate drying, firing and cooling time, and to minimize thermal gradients within the body. This also makes them lighter and conserves clay. The consistency of the mix can be damp to wet (18-25% moisture content is typical), but it is usually extruded as dry as possible so that the green product can be handled without delay and to save fuel (Figure. 2.1) [18, 19].

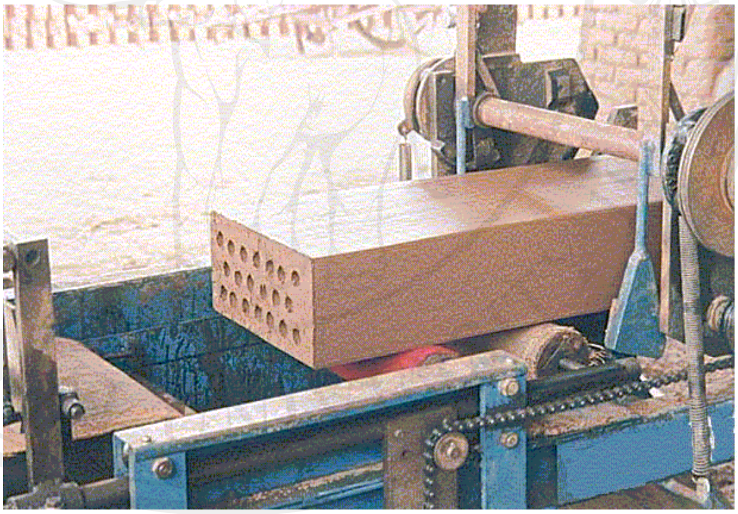

Figure. 2.1 Extrusion for making clay bricks [20].

- Stiff-plastic pressing: Bricks are formed at somewhat lower moisture content, typically 14-17%, in box-like moulds. Each clay body is pressed twice, initially to give it the rough brick shape and subsequently to impart sharp corners and a central depression or frog.

- Dry pressing: In this process, bricks are actually damp pressed, at moisture content around 10%. This process has been largely superseded by extrusion, but it does eliminate the drying stage and associated shrinkage (Figure. 2.2).

Figure. 2.2 Dry press process for making clay bricks [21].

- Handmade bricks: The handmade process involves the throwing of a suitably sized clot of wet clay into a wooden mould on a bench. The surplus clay is struck off with a framed wire and the green brick removed. The bricks produced are irregular in shape with soft arrises and interestingly folded surfaces. Two variation of the process are pallet moulding and slop moulding (Figure. 2.3) [18].

Figure. 2.3 Handmade for making clay bricks [22].

In pallet moulding, a stock board, the size of the bed face of the brick, is fixed to the bench. The mould fits loosely over the stock board, and is adjusted in height to give appropriate thickness to the green brick. The mould and board are sanded to ease removal of the green brick which, is produced with a frog or depression on one face [19].

2.3 Different forms of bricks

Some of the common types of bricks, depending upon the places of use, are shown in Figure. 2.4. Round ended and bull nosed bricks (Figure. 2.4 (a, f)) are used to construct open drains. For door and window jambs, cant bricks, also called splay bricks, shown in (Figure. 2.4 (b, c)), are most suitable. The double cant brick shown in (Figure. 2.4 (c)) is used for octagonal pillars. Cornice brick shown in (Figure. 2.4 (d)) is used from architectural point of view. (Figure. 2.4 (e)) shows a compass brick—tapering in both directions along its length—used to construct furnaces. Perforated brick (Figure. 2.4 (g)) is well burned brick, but is not sound proof. Figure 2.4 (h) shows hollow bricks. These are about l/3rd the weight of normal bricks and are sound and heat proof, but are not suitable where concentrated loads are expected. Top most bricks course of parapets is made with coping bricks shown in (Figure. 2.4 (i)). These drain off the water from the parapets. Brick shown in (Figure. 2.4 (j)) is used at plinth level and for door and window jambs. Split bricks are shown in (Figure. 2.4 (k, 1)). When the brick is cut along the length, it is called queen closer and when cut at one end by half header and half stretcher, it is known as king closer [23].

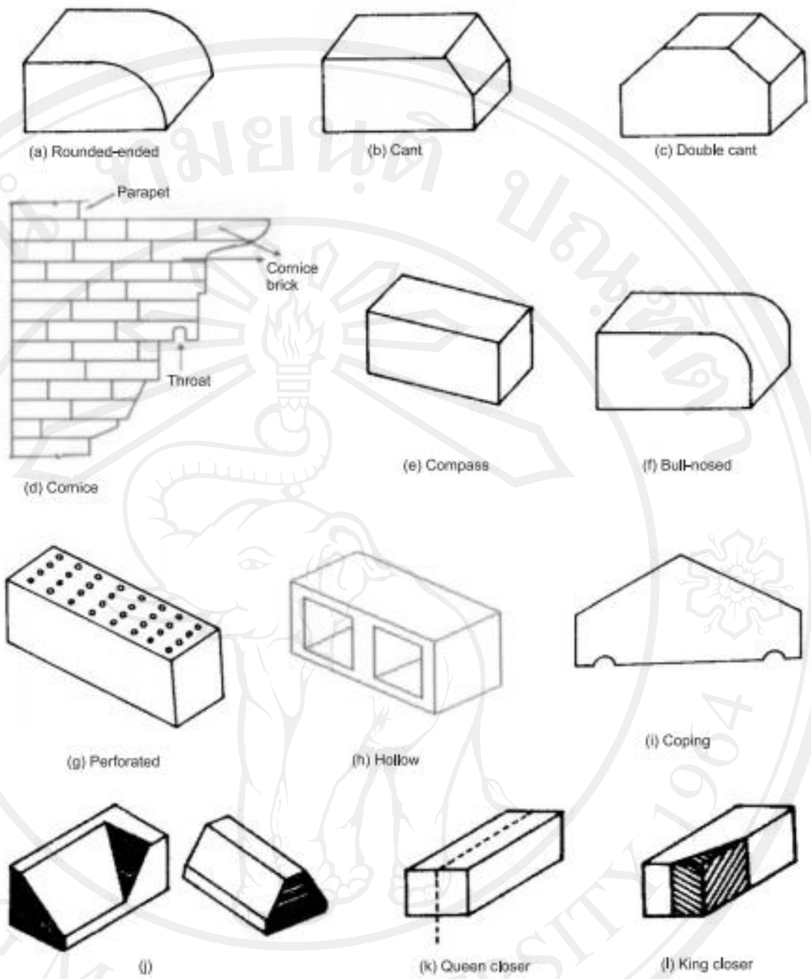

Figure. 2.4 Forms of bricks [23].

2.4 Defects of bricks

Over-burning of bricks: Bricks should be burned at temperatures at which incipient, complete and viscous vitrification occur. However, if the bricks are overburnt, a soft molten mass is produced and the bricks loose their shape. Such bricks are not used for construction works.

Under-burning of bricks: When bricks are not burnt to cause complete vitrification, the clay is not softened because of insufficient heat and the pores are not closed. This results in higher degree of water absorption and less compressive strength. Such bricks are not recommended for construction works.

Bloating: This defect observed as spongy swollen mass over the surface of burned bricks is caused due to the presence of excess carbonaceous matter and sulphur in brick-clay.

Black core: When brick-clay contains bituminous matter or carbon and they are not completely removed by oxidation, the brick results in black core mainly because of improper burning.

Efflorescence: This defect is caused because of alkalies present in bricks. When bricks come in contact with moisture, water is absorbed and the alkalis crystalise. On drying grey or white powder patches appear on the brick surface. This can be minimised by selecting proper clay materials for brick manufacturing, preventing moisture to come in contact with the masonry, by providing waterproof coping and by using water repellent materials in mortar and by providing damp proof course.

Chuffs: The deformation of the shape of bricks caused by the rain water falling on hot bricks is known as chuffs.

Checks or cracks: This defect may be because of lumps of lime or excess of water. In case of the former, when bricks come in contact with water, the absorbed water reacts with lime nodules causing expansion and a consequent disintegration of bricks, whereas shrinkage and burning cracks result when excess of water is added during brick manufacturing.

Spots: Iron sulphide, if present in the brick clay, results in dark surface spots on the brick surfaces. Such bricks though not harmful are unsuitable for exposed masonry work.

Blisters: Broken blisters are generally caused on the surface of sewer pipes and drain tiles due to air imprisoned during their moulding.

Lamination: These are caused by the entrapped air in the voids of clay. Laminations produce thin lamina on the brick faces which weather out on exposure. Such bricks are weak in structure [23].

2.5 Burning of clay brick

Firing transforms the raw clay brick into a rigid, continuous (although usually porous) ceramic by way of a complicated succession of physical and chemical changes. The green clay even after preliminary drying contains as much as 10% by weight of free water which is lost rapidly as the kiln temperature rises above 100 ^{o}C. The clay minerals illite, montmorillonite and halloysite also contain weakly bound water within their lattice structures, which is readily lost (150-200 ^{o}C). Further water is evolved as the clay minerals themselves decompose between about 400 ^oC and 700 ^oC, leaving a residue of preponderantly non-crystalline material, mainly silica and alumina. At about 900 ^oC crystalline silica, alumina and spinel compounds appear and the mineral mullite $3Al_2O_3.2SiO_2$ forms above about 1000 ^oC. The minor oxide constituents Na_2O, K_2O, MgO, CaO and FeO produce relatively low melting eutectic mixtures with principal components SiO_2 and Al_2O_3, so that some melting may occur below 1000 ^oC. This marks the onset of vitrification which promotes sintering of individual clay particles. During this period dimensional shrinkage of up to 15% occurs. The temperature range for vitrification and the viscosity of the liquid phase depend on the clay composition. Firing ultimately produces a consolidated but porous mass which contains both microcrystalline mullite and vitreous material, together with unchanged quartz.

Clay composition and chemical changes during firing also influence the final colour of bricks. The main strongly coloured constituent of brick ceramic is ionic iron; after kiln firing under oxidizing conditions the iron is present in the ferric Fe (III) oxidation state and red brick colours are obtained. It reducing conditions exist during the last stages of firing because of limited air supply or deliberate injection of fuel into the kiln atmosphere to remove oxygen, iron is present in the ferrous Fe (II) oxidation state or more probably in the mixed Fe (II)/Fe (III) states, and blue or bule-black ceramic colours are produced. These colours may be masked, muted or otherwise modified by other constituents, notably lime. Large amounts of lime produce buffs and yellows. Considerable variation of colour may be found on individual bricks and within a single batch of bricks, which may be sorted for colour after drawing from the kiln [24].

2.6 Characteristics of good brick

The essential requirements for building bricks are sufficient strength in crushing, regularity in size, a proper suction rate, and a pleasing appearance when exposed to view.

Size and shape : Brick should have a uniform deep red or cherry colour as indicative of uniformity in chemical composition and thoroughness in the burning.

Colour : Brick should have a uniform deep red or cherry colour as indicative of uniformity in chemical composition and thoroughness in their burning of the brick.

Texture and compactness : Surfaces of bricks should not be too smooth to cause slipping of mortar. Bricks should have precompact and uniform texture. A fractured surface should not show fissures, holes grits or lumps of lime.

Hardness and soundness : Bricks 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.

Water absorption : Water absorption of bricks should not exceed 20 % of their dry weight when kept immersed in water for 24 hours.

Crushing strength : Crushing strength of bricks should not be less than 10 N/mm^2.

Brick earth : Brick earth should be free from stones, kankars, organic matter, saltpetre, etc [23].

2.7 Moisture expansion of clay bricks

Moisture expansion of bricks and other burned clay products is generally attributed to the hydration of amorphous materials or glassy in the brick that have formed during the burning of the clay. State that this expansion apparently involves the bricks non-crystalline, high-energy phases, which are the amorphous alkali of clay minerals or the low-temperature glass formed from the alkali content of the clay. This also points to the hydration of amorphous materials and glassy in brick as the cause of moisture expansion. Researchers note, in addition, that when bricks are fired at low temperatures, the re-hydration of dehydrated clay mineral causes expansion [25]. Moisture expansion is progressive and continues indefinitely, although at a diminishing rate, such that the total expansion increases roughly. Thus flet-tons fired at 1050 ^{o}C showed increases in length of 0.02% at 10 days, 0.04% at 100 days and 0.06% at 1000 days. The expansion rate depends on the mineralogy of the fired clay and to a marked extent on the porosity and the maximum firing temperature, but it is not greatly influenced by exposure conditions. Bricks made from clay with high lime contents (notably Gault clays) give low expansions as little glassy material is present in the fired ceramic [24, 25].

2.8 Coefficient of thermal expansion of clay bricks

Clay brick is a burned clay masonry unit, generally rectangular and solid. The term "brickwork" refers to masonry built with bricks and mortar, primarily as vertical members subjected to compressive and bending forces. The coefficient of thermal expansion of brickwork is approximately 5-7 x 10^{-6} per °C, which is about half that of concrete and twice that of limestone. The expansion of clay brick from moisture is about one-fifth that of concrete [26].

2.9 Heat transfer by conduction

Basic law of conduction

The basic relation for heat flow by conduction is the proportionality between heat flux and the temperature gradient. It is known as *Fourier's law,* which for steady one-dimensional flow in the *x* direction has already (Equation 2.1).

$$\frac{dq}{dA} = k\frac{dT}{dx} \tag{2.1}$$

Where q is the rate heat flow in direction normal to surface (W), k is the thermal conductivity (W/m K), dA is the surface area (m^2), dT is the temperature difference, the thickness (K) and dx are the distance measured normal to surface (m)[27].

2.10 Thermal conductivity

Thermal conductivity is the property of material that plays a key role in all heat transfer; it may be in the context of energy efficient building design or calculation of temperature profile in structure. Most of the ceramic construction materials, such as bricks, block and concrete (chemically combined), are porous in nature, largely having interconnected pores. Heat transfer in such materials is a complex process and involves many components. The most important of these components are: (1) heat conduction in solid materials, (2) convection heat transfer through pore fluid and (3) radiation from solid surfaces of pores.

1. Conduction, in which the heat is transferred by bond vibration of the hotter substance to the cooler substance and so setting up a corresponding motion amongst the atomic structure in the latter, the acceleration of motion progresses at a definite rate through the second substance. The ease at which the heat passes through a material-as measured by the rise in temperature of the latter-is termed "thermal conductivity".

As a result of their different atomic structure and electron configurations, materials have different powers of conducting heat. Most metals have a higher thermal conductivity than non-metals or compounds, i.e. they conduct heat rapidly through their mass.

2. Convection, in which the heated particles move away from the hotter to the cooler parts of the mass and carry "heat" with them. Convection can only occur in fluids, as the particles in a solid are not sufficiently mobile.

3. Radiation, in which the heat is carried neither by conduction nor convection, but in a manner comparable to the transmission of light. Heat may be radiated instantaneously through air and other gases, and when so radiated it scarcely affects the temperature of the medium through which the "rays of heat" are passed. There is a very close relationship between radiated heat and light. Both are forms of electromagnetic radiation differing only in wavelength.

Hence, when a body is sufficiently heated, the heat rays emit a form of light and the body is said to be "incandescent". When heat rays are absorbed by any substance the latter is heated and its temperature increased in proportion to the amount of heat absorbed, but the air through which the heat rays pass may remain at a much lower temperature. This is due to the fact that radiated heat is absorbed more by some surfaces than others, the nature of the surface being of greater importance, in this respect, than the composition of the heat absorbing material. Similarly, the amount of heat radiated from a body varies according to the colour and nature of the radiating surface, being low for polished metal and high for rough, black surfaces. In the latter, it is proportional to the fourth power of the absolute temperature.

The proportionality constant *k* is a physical property of the substance called the thermal conductivity. It like the Newtonian viscosity μ is one of the so-called transport properties of material. This terminology is based on the analogy between Equation $\tau_v = \frac{\mu}{g_c}\frac{du}{dy}$ and (2.1), the quantity τ is a rate of momentum flow per unit area, the quantity *du/dy* is the velocity gradient, and μ is the required proportionality factor. In Equation (2.1), *q/A* is the rate of heat flow per unit area, *dT/dx* is the temperature gradient, and k is the proportionality factor.

In engineering unit, q is measured in watts or Btu/h and *dT/dx* in ^{o}C/m or ^{o}F/ft. Then the units of *k* are W/m.^{o}C or Btu/ft^{2} .h. (^{o}F/ft), which may be written Btu/ft.h. ^{o}F.

Fourier's law states that *k* is independent of the temperature gradient but not necessarily of temperature itself. Experiment does confirm the independence of *k* for a wide range of temperature gradients, except for porous solid, where radiation between particles, which does not follow a linear temperature law, becomes an important part of the total heat flow. On the other hand, *k* is a function of temperature, but, except for some gases, not a strong one. For small ranges of temperature, *k* may be considered constant. For larger temperature ranges, the thermal conductivity can usually be approximated by an equation of the form

$$k = a + bT \tag{2.2}$$

where a and b are empirical constants.

Thermal conductivities of metals cover a wide range of values, from about 17 W/m. ^oC (10 Btu/ft.h. ^oF) for stainless steel and 45 W/m. ^oC (26 Btu/ft.h. ^oF) for mild steel, to 380 W/m. ^oC (220 Btu/ft.h. ^oF) for copper and 415 W/m. ^oC (240 Btu/ft.h. ^oF) for silver. The thermal conductivity of metals is generally nearly constant or decreases slightly as the temperature is increased, and the thermal conductivity of alloys is less than of pure metals. For glass and most nonporous materials, the thermal conductivity are much lower, from about 0.35 to 3.5 W/m. ^oC (0.2 to 2 Btu/ft.h. ^oF); for these materials k may either increases as the temperature rises.

For most liquids k lower than that for solids, with typical values of about 0.17 W/m. ^oC (0.1 Btu/ft.h. ^oF), and k decreases by 3 to 4 percent for a 10 ^oC rise in temperature. Water is an exception, with k = 0.5 to 0.7 W/m. ^oC (0.3 to 0.4 Btu/ft.h.^oF), and k goes through a maximum as the temperature is raised.

Gases have thermal conductivity and order of magnitude lower than those for liquids. For an ideal gas, k is proportional to the average molecular velocity, the mean free path, and the molar heat capacity. For monatomic gases, a hard-sphere model give the theoretical equation.

$$k = \frac{0.0832}{\sigma^2}\left(\frac{T}{M}\right)^{\frac{1}{2}} \tag{2.3}$$

where T = temperature, K

M = molecular weight

σ = effective collision diameter, Å

k = thermal conductivity, W/m K

Equation (2.3) generally underestimates the thermal conductivity of polyatomic gases, which have higher heat capacities than monatomic gases because of the rotational and vibrational degrees of freedom. The higher heat capacities can also make k increase quite rapidly with temperature. A change from 300 *k* to 600 *k* may increase the thermal conductivity 3 to 4 fold. Several methods of predicting *k* for gases and gas mixtures are reviewed by Reid et al. The thermal conductivity of gases is nearly independent of pressure up to about 10 bars, at higher pressures *k* increases slightly with pressure. Values of *k* for some solids, liquids, and gases are given in apps. 6 and 10 through 13. More complete tables are available in the literature.

Solids which have low thermal conductivity are used for insulation on pipes, vessels, and buildings. Porous materials such as fiberglass pads or polymer foams act by entrapping air and eliminating convection. Their *k* values may be nearly as low as that of air itself, and if a high-molecular-weight gas is trapped in a closed-cell foam, *k* can be less than that for air (Table 2.1) [27-29].

Table 2.1 Approximate values of thermal conductivity type of bricks different temperature [29].

Type of bricks	Temperature (^oC)	Thermal conductivity (k) (Btu/h-ft-^oF)	Thermal conductivity (k) (W/m K)
Alumina	1351	2.70	4.67
Building brick work	**20**	**0.40**	**0.69**
Carbon	-	3.00	5.19
Fire clay (Missouri)	200	0.58	1.00
	1000	0.95	1.64
	1400	1.02	1.77
Kaolin Insulating Firebrick	200	0.050	0.09
	760	0.113	0.20
Silicon carbide, recrystalized	600	10.7	18.52
	1000	8.0	13.85
	1400	6.3	10.90

Source: Unit Operation of Chemical Engineering, Warren L. McCabe et.al. (1993)

1 Btu/h-ft-^oF = 1.730734 W/m K Table N-21 Thermal Conductivity, Power Plant Technology, McGRAW-Hill International Edition.

2.11 Steady-state conduction

Simple examples of steady-state conduction are shown in Figure 2.5. In Figure 2.5a, a flat-walled insulated tank contains a refrigerant at perhaps -10 ^{o}C, while the temperature of the air outside the tank is 28 ^{o}C.

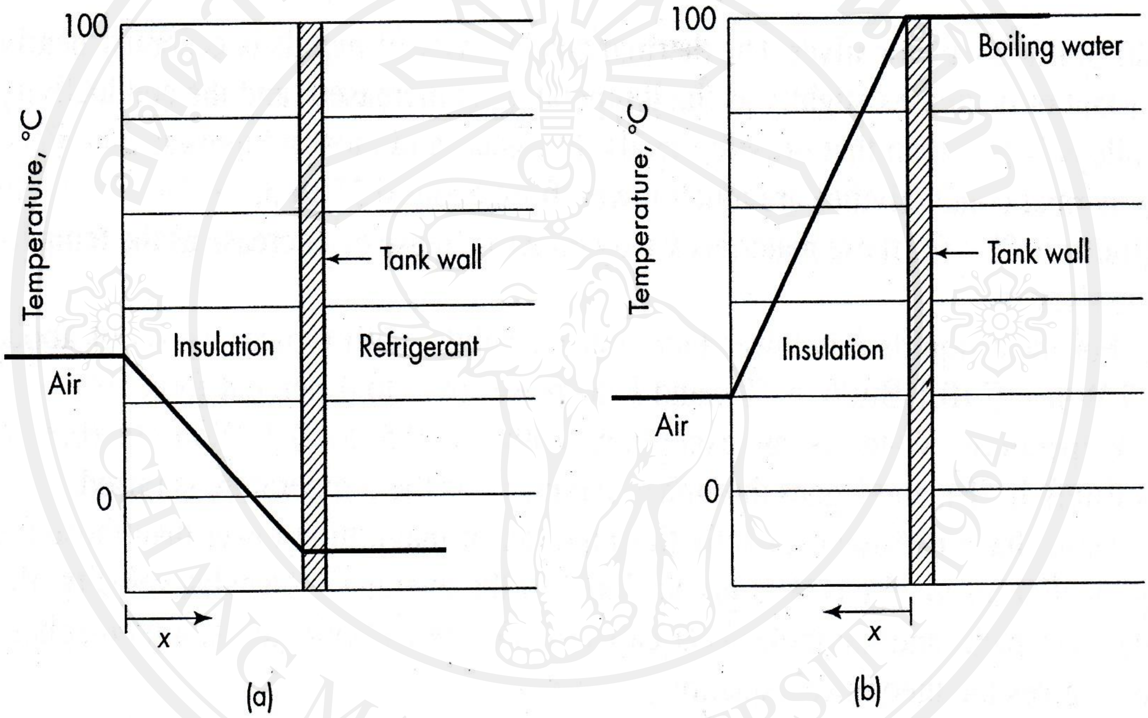

Figure. 2.5 Temperature gradients outside insulated tank (a) heat flow into tank and (b) heat flow from the tank [27].

The temperature falls linearly with distance across the layer of insulation as heat flows from the air to the refrigerant. As we will see in a later chapter, there may actually be a temperature drop between the bulk of the air and the outside surface of the insulation, but it is assumed to be negligible in (Figure. 2.5 (a)). Figure. 2.5 (b) show a similar tank containing boding water at 100 ^{o}C, losing heat to air at 20 ^{o}C. As before, the temperature profile in the insulation is linear, but heat flow in the opposite direction and x in Equation (2.1) must be measured outward from the inside surface. Again, there may be a temperature change in the air near the tank wall; again it is assumed to be negligible.

The rate of heat flow is found as follows: assuming that k is independent of temperature. Since in steady state there can be neither accumulation nor depletion of heat within the slab, q is constant along the path of heat flow. If x is the distance from the hot side, Equation (2.1) can be rewritten as

$$dT = -\frac{q}{kA}dx$$

Since the only variables in this equation are x and T, direct integration gives

$$\frac{q}{A} = k\frac{T_1 - T_2}{x_2 - x_1} = k\frac{\Delta T}{B} \tag{2.4}$$

where $x_2 - x_1 = B$ = thickness of layer of insulation

$T_1 - T_2 = T$ = temperature drop across layer

When the thermal conductivity k varies linearly with temperature, in accordance with Equation (2.2), Equation (2.4) still can be used rigorously by taking an average value for k, which may be found either by using the arithmetic average of the individual values of k for the two surface temperature T_1 and T_2, or by calculating the arithmetic average of the temperature and using the value of k at that temperature.

Equation (2.4) can by written in the from

$$\frac{q}{A} = \frac{\Delta T}{R} \tag{2.5}$$

where *R* is the resistance of the solid between point 1 and 2. Equation (2.5) is an instance of the general rate principle, which equates a rate to the ratio of a driving force to a resistance. In heat conduction, *q* is the rate and ΔT is the driving force. The resistance *R*, as shown by Equation (2.5) $\bar{k}$ and using for *k* to account for a linear variation of *k* with temperature, is $B/\bar{k}$. The reciprocal of a resistance is a heat-transfer coefficient h, as in Newton's law. For heat conduction, then, $h = \bar{k}/B$. Both *R* and *h* depend on the dimension of solid as well as on the thermal conductivity *k*, which is a property of the material [27].

2.12 Porous materials

Porous materials are characterized by the variety of size and shapes that form their pore structure. Some pores are so small that they cannot be regarded as pores, but more like imperfections in the crystal structures. Others are so big, that they should rather be described as cavities or cracks. Usually pores are regarded as such, when they hold size from 1nm to 1mm.

A Simple way to characterize the pores is the total volume of the open pores, the porosity. A more detailed description is given by the pore size distribution. Here the pore volume is divided into fractions of pores, that have the same as cylindrical pore with a certain equivalent radius. This way the porosity becomes a function of the so called equivalent pore radius [30].

Most of the building materials are composites and their thermal parameters represent the effect resulting from the properties of their particular phases and components. Usually the composite consists of the bonding matrix, aggregate and pore space. The thermal conductivity of the dry porous material is given by the properties of the solid phase as a whole and by the pore volume. The known relationships among the solid phase properties pore structure parameters and material thermal parameters enable model thermal properties of the porous materials only from the knowledge of properties of the solid phase and the pore space [31]. Therefore, the following classification is proposed (Figure. 2.6 a-d).

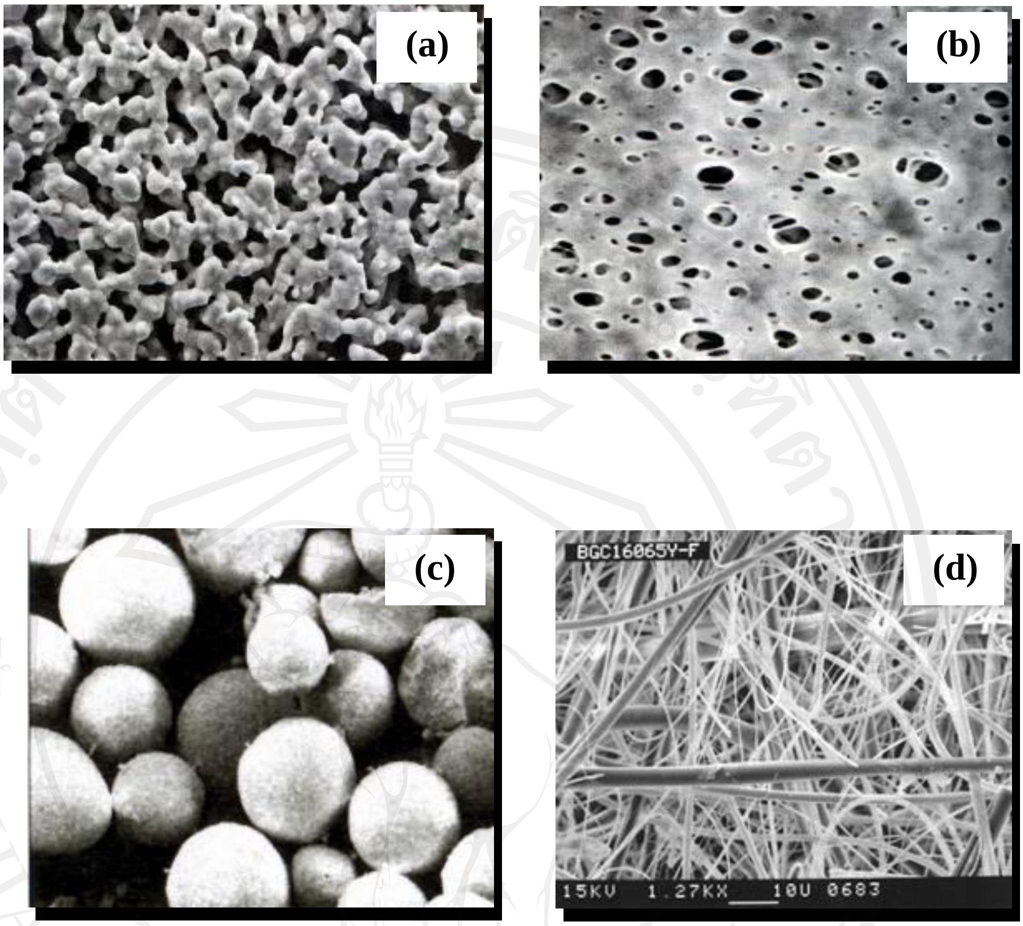

Figure. 2.6 Typical pore structure [32].

(a) Materials in which the voids are created through the injection of water into a molten mass. This procedure is used in the production of some synthetic materials (silicon carbide, corundum, ferrosilicon) and of expanded aggregates (expanded slags) used as insulating materials in the building industry. Also in this class of materials the voids are roundish but are generally interconnected.

(b) Materials in which the voids result from the evolution of gas inside a molten mass. Such phenomena occur in nature and lead to the formation of various types of extrusive volcanic rocks. The gases dissolved in the magma evolve as a consequence of a reduction in pressure, which leads to the formation of holes.

A typical example is pumice, a glassy, vesicular rock of acid composition which is used as abrasive, thermal and acoustic insulator, filter aid, etc. Other volcanic rocks, such as trachyte and basalt, may be porous, though in many cases the pores are filled with clay resulting from degradation of the rock. The evolution of gas can also be utilized to produce artificial porous materials, e.g. expanded clay. In this case various gases are produced (CO, CO_2, SO_2, SO_3, etc.) during firing at 1150-1250°C. In all these materials the voids are roundish, not or only partially interconnected and separated by a homogeneous matrix.

(c) Materials resulting from grain sedimentation processes followed by lithification, through which the sediment is converted to more or less porous rock. A typical case are the arenaceous rocks consisting of rounded to subrounded particles.

(d) Materials in which the porosity is due to microcracks and fractures resulting from stresses and strains in the rock. The porosity is low, unless there has occurred a dilation or expansion in volume of the particle mass during the fracture formation. This type of porous materials are mentioned here for the sake of completeness, but will not be considered in the following sections [33].

2.13 Porosity

Porosity is an important microstructural feature in most natural and man-made materials and often affects significantly physical properties of these materials such as fluid permeability, thermal conductivity, electrical conductivity, dielectric constant, magnetic permeability, diffusion coefficient, acoustic wave velocities and elastic moduli and yields rupture or ductile strength (Figure. 2.8).

The porosity of material is a major factor in influencing its thermal conductivity, but no simple relationship can be postulated of the complexity of the various factors involved. Air is a vastly superior insulating material to most solid bodies, so that a highly porous body will be less conductive than a solid body of the same chemical composition.

The actual conductivity value will depend not only on the total void space, but also on the size and nature of the void whether they are closed or interlinked. These factors are important because heat can be transferred across an air space by conduction, radiation and convection. Although some authors question whether convection can be an acceptable mechanism of heat transfer in porous bodies, it cannot be denied that heat differentials will result in air flow through a body if continuous pores are present.

Although, at sight, a body with large pores might be more insulating than one with small pores but with the same total porosity, this is not the case. There are many explanation advanced for this, not all of which are agreed by various authorities. In a system of small holes, however, the path length through the solid from hot face to cold face must be far greater than is the case when only a few large holes are present. For this reason alone, the conductivity of small pores material would be less than a large-holed-specimen of equal total porosity.

Because of the complicating factor of pores size, the relationship between thermal conductivity and total porosity is best represented by a band spread of the type shown in (Figure. 2.4), for a range of alumino-silicate products. The actual chemical composition varied between 22-24 percent Al_2O_3 firing temperatures to which the bodies has been subjected were between 1000-1450 ^{o}C. Hence, variables other than total porosity are involved, but these would not result in a major order of difference.

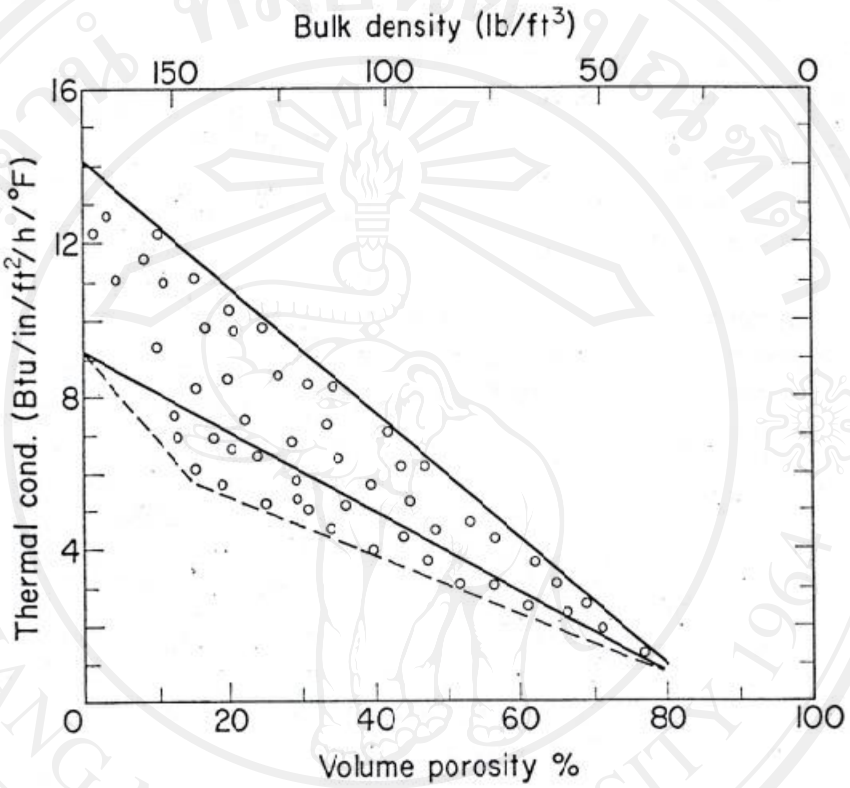

Figure. 2.7 The relationship between thermal conductivity and volume porosity for some alumino-silicate bodies [29].

Bricks of lower alumina content and those containing the highest percentage of glassy phase usually fall nearer to the line of lower values. Some of the bricks included in Fig 2.7 were actually building bricks. Those which were hard-fired and composed of Coal Measure shales, fell within the band spread of the full lines, but towards the lower limit, Common bricks of high porosity, particularly those rich in lime, fell outside the normal band spread for refractory materials of similar porosity.

Common bricks vary in thermal conductivity values between 3.0-10.0 Btu.s/in/ft^2/h/F or 0.4-1.45 w/m K.

The permeability of bricks to air has a marked influence on thermal conductivity values. Bricks of equal porosity and similar composition have a higher thermal conductivity when they are permeable than when appreciable closed pores are present. Under normal service conditions, when gaseous atmospheres are involved, the apparent thermal conductivity can be many times greater in a permeable body [28-29, 34].

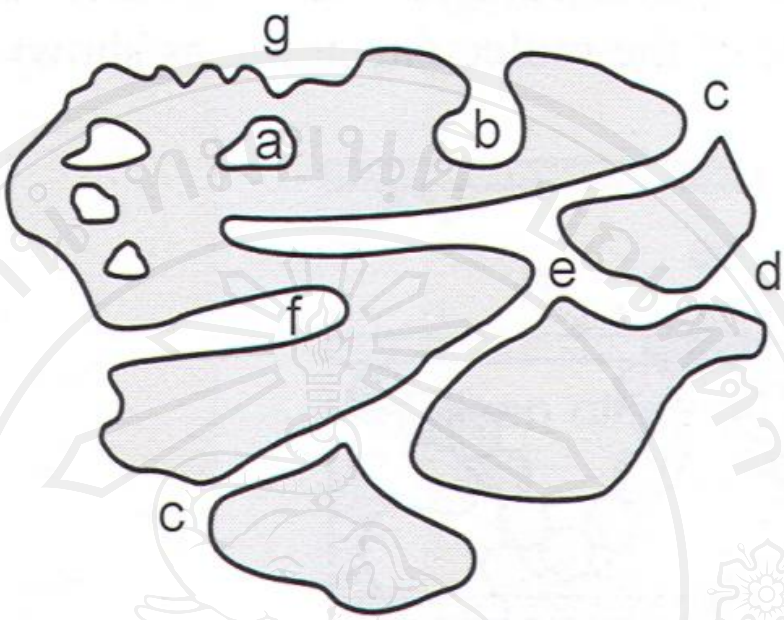

Figure. 2.8 Different types of pores [35].

Accessibility: a: closed pores, b,c,d,e,f: open pores, b, f: blind pores (dead-end or saccate) and e: through pores ;Shape: c: Cylindrical open, f: Cylindrical blind, b: ink-bottle-shaped , d: funnel shaped and g: roughness.

2.14 Additives for pore forming

Demir [5] investigated the use of organic residues (sawdust, tobacco residues and grass) in clay bricks by-products of industries and agriculture. Amounts of organic residues were studied (0%, 2.5%, 5% and 10% weight.) by mixing with raw brick-clay. Samples were fired at 900 ^{o}C. It was found that the organic residues could be effectively used for pore-forming for up to 5% residue addition by weight; further addition was not very effective for decreasing the bulk density of the clay body. The residues increased the open porosity and decreased the bulk density. This effect may improve the thermal insulation properties and low dead load in buildings.

Okunade, E. A. [36] used wood ash and sawdust as admixtures in laterite-clay bricks. Sawdust (for burning out) and wood ash admixtures with ratio of 70:30 by weight laterite-clay were investigated. The admixtures were added in various combinations of proportions by volume (from 0 to 10%). This had resulted in denser products with high compressive strengths (with 0% sawdust and 10% wood ash), high softening coefficient, low water absorption rates, low saturation coefficient, low abrasion index, especially with addition of wood ash admixture solely.

Demir *et al.* [37] investigated the utilization potential of kraft pulp as residues in clay bricks. Amount of residue (0%, 2.5%, 5% and 10% by weight) was mixed to raw brick clay. Samples were fired at 900 ^{o}C. The result showed that the pulp residue could be effectively used for pore-forming up to 5% addition levels; further addition was not effective for the decreasing of the bulk density of the clay body. Compressive strength of the samples was decreased by addition of the residue.

Demir [38] investigated the utilization potential of processed waste tea (PWT) in clay brick. Afterwards, in order to get comparable results, different ratios of the waste (0, 2.5 and 5% by mass) were added to the raw-brick clay. It was found that the waste additive increased the open porosity, decreased the bulk density and improved the thermal insulation properties and compressive strength values increasing the amount of waste additive.

Ugheoke, B. J., *et al.* [39] investigated the use of kaolin - rice husk insulating fire – bricks. Kaolin, plastic clay and rice husk, respectively mixed at ratio 4:1:2 by gram and fired at 1200 ^oC. The results showed the values of shrinkage: 9.7% - 13.6%; effective moisture content: 28.34% - 32.52%; modulus of rupture: 4.26 kgf/cm^2 - 19.10 kgf/cm^2; apparent porosity: 56% - 95.93%; water absorption: 42.27% - 92.12%; bulk density: 1.04 g/cm^3 - 1.41 g/cm^3; apparent density: 2.56 g/cm^3 - 5.77 g/cm^3; and thermal conductivity: 0.005 W/m K - 0.134 W/m K.

Jung *et al.* [40] studied addition of the coal wastes to clay bricks. The mixed bricks were calcinations at 900-1400 ^oC. Clay bricks were prepared by mixing the brick body to 10-50% coal waste. It was found that the water absorption of the brick specimens was increased linearly when mixed amount and decreased with increasing calcinations temperature. At a certain temperature, compressive strength decreased when increasing amounts of waste. At 1300 ^oC when coal waste was added in to clay more than 30%, it was found that water absorption was $<$ 10%, compressive strength $>$ 210 kgf/cm^2.

Rahman [41] investigated properties of clay-sand-mixes in various percentages of rice husk ash (RHA). Time of burning at 1000 ^{o}C was studied (2, 4 and 6 hours). It can be seen that 4 hours of firing duration was suitable to produce lightweight bricks.

Sutcu and Akkurt [15] used paper making light-weight bricks to reduce thermal conductivity and gain acceptable compressive strength. The mixed brick was prepared by using at different ratios (up to 30 by weight), then fired at 1100 ^{o}C. The result showed that the fired density of the brick reduced to 1.28 g/cm^3 when paper processing residues was decreased. Moreover compressive strengths and thermal conductivity of brick samples were higher than commercial bricks. Compressive strengths of the brick samples produced in this study were higher than required by the standards. Thermal conductivity of the porous brick produced in this study (<0.4 W/m K) showed more than 50% reduction compared to local brick of the same composition (0.8 W/m K).

Bánhidi and Gömze [42] investigated the using of agricultural byproducts which were also ranked based on their effect on the product's thermal properties. The industry relevant amounts of additives sawdust, rice-peel, seed-shell of 0, 4 and 7 percentages by weight were added to the basic clay composition. The samples were fired at a standard industrial temperature (900 ^{o}C). It was found that the thermal conductivity was largely decreased when sunflower seed-shell additive was used and when 7% weight of seed shell was added to the clay. The thermal conductivity of the fired product was decreased from 0.27 W/m K to 0.17 W/m K (36%). In some ways under the same conditions the sawdust caused the least improvement, only a decrease of 0.27 W/m K to 0.23 W/m K (16%) was measured.

Onche *et al.* [43] studied the effect of rice husk and diatomite on the insulating properties of kaolin-clay firebrick. Mixing ratios of 3:2:4:1 representing weight in grams of kaolin, plastic clay, rice husk and diatomite. Five fired brick samples of different composition were fired at 900 ^{o}C, 1000 ^{o}C, 1100 ^{o}C and 1200 ^{o}C. It was found that at 1200 ^{o}C, the modulus of rupture is 22.57 kgf/cm^2, apparent porosity is 98.25%, apparent density is 2.83 g/cm^3, bulk density is 1.11 g/cm^3 and thermal conductivity is 0.38 W/m K.

Karaman *et al.* [8] investigated the effect of pumice on some physical and mechanical properties of clay brick. The pumice amount in the mixture varied from on 0 to 90% with 10% interval. The brick was fired under various firing temperature at 800, 900 and 1000 ^{o}C. The result showed that bricks fired at higher temperatures exhibited higher compressive strength at a given pumice ratio. Increasing rate of pumice added to clay gradually decreased the density of the final products, showing that it is possible to produce cheaper and lighter bricks with pumice addition. Heat conductivity directly affects energy saving. Therefore, due to high thermal insulation of light bricks, considerable energy saving was possible. The pumice could be effectively used to from porous bricks up 50% addition levels; further additions resulted in excessive water absorption of bricks which was not desired.

Russ *et al.* [44] investigated the using of spent grains, a by-product of the brewing industry, added to increase porosity in brick. Afterwards, in order to get comparable result, ratio of the waste (3.5% by mass) was added to the raw-brick clay.

Samples were fired at 950 °C. It was found that the fired finished bricks produced with spent possessed a similar or higher strength, a higher porosity (higher water absorption capacity) and a lower density than those produced from a similar production clay.

Elinwa [45] studied the effect of adding sawdust ash (SDA) to clay to improve bricks properties. Amounts were studied by increasing sawdust ash from 0% (control), 10%, 20%, 30% and 40% by mass of clay. Brick contained with SDA was fired at 200 ºC, 600 ºC and 1200 ºC and cured for 1, 4 and 8 days. It was found that the suitable condition was 10% SDA replacement and 600 °C firing temperature. Maximum compressive strength was achieved at 1-day curing. Water absorption was increased and so was the ash content. The greatest water absorption was recorded at 600 °C.

Ramadn *et al.* [46] used sludge as partial substitute for clay in brick manufacturing. In this study, four different series of sludge with ratios 50, 60, 70 and 80 percent of the total weight of sludge-clay mixture and was fired at 950, 1000, 1050 and 1100 °C. It was found that compressive strength was between 23.49 and 118.94 kg/cm^2 except the two brick types that contained 80 percent sludge ratio and fired at 950 and 1000 °C.

Partong [47] studied mechanical, thermal and physical properties of clay bricks which were made from fly ash, gypsum and clay. Mixing ratios of fly ash were 0, 20 and 40% and the percentages of gypsum were 0, 10 and 20% by weight. Samples were fired at 1000 °C. It was found that the compressive stress and bending moment of bricks were at the percentage of gypsum of 10%. The compressive stress and bending moment of bricks were decreased when the percentages of gypsum was higher or lower than 10% for all percentages of fly ash. However both of compressive stress and bending moment of bricks were decreased with the percentage of fly ash higher than 0% and slightly increased with the percentage of fly ash higher than 20%. When fly ash mixture was increased, thermal conductivity was decreased.

Chopradub [48] studied the effect of the rice husk on physical properties of clay building bricks which were made from mixture of rice husk and clay. Proportion of rice husk and clay varied from 0, 3.4, 4.9 and 7.8% by dry weight. Dried green bricks were fired at 800, 1000 and 1200 ^{o}C. The results indicated that addition of rice husk led to the reduction of compressive strength and the compressive strength reduction rate being greater than porosity increasing rate. The water absorption rate increased with the porosity. Thermal conductivity and water absorption rate were reduced when the proportion of rice husk were increased. The most suitable brick in terms of physical properties, production time and energy was made from a mixture of 2.2% rice husk fired at 800 ^{o}C with compressive strength and water absorption of these bricks of 35 kg/cm^2 and 24%, respectively.

Ten *et al*. [49] investigated influence of the mineralogical composition of the starting raw materials mixture on the thermal conductivity and mechanical strength of clay brick products. The findings suggest that using illitic-kaolinitic clays is advised to manufacture traditional ceramics with high thermal insulation and appropriate mechanical properties. Large-sized potassium feldspar and quartz particles adversely affect fired mechanical strength. The addition quartz gives high thermal conductivity. While, the addition of carbonates or the use of calcareous clays has a positive effect on mechanical strength, because carbonate acts as a pore-forming agent crystalline phases during firing that enhance mechanical strength.

Gualtieri *et a.l* [50] studied thermal conductivity, physical, chemical and mineralogical of representative commercial clays from 9 different quarries in Northern Italy from the mining districts. The effective thermal conductivity of the fired bricks was determined and correlated with physical and mineralogical properties of the raw materials. The results indicated that the organic content and the grain size distribution significantly influenced the effective thermal conductivity but not for the carbonate content. The pore forming action of organic material had a positive influence on the thermal insulation. Instead, the thermal insulation decreased with decreasing particle size, possibly due to an increased sintering rate during brick firing.

Ten *et al.* [51] investigated influence on bulk density and firing temperature against the thermal conductivity and mechanical strength of traditional ceramic materials. For the studied clay, variation of thermal conductivity with total porosity followed the expected trend when the firing temperature was above 1000 ^{o}C. The results indicated that thermal conductivity can be reduced in this type of material by increasing green porosity (or by adding organic lighteners) and/or lowing the firing temperature.

Bhattacharjee and Krishnamoorthy [52] studied the influence of porosity on thermal conductivity of construction materials. Three types of materials with wide porosity variation (dense concrete, burnt clay brick and concrete blocks) were chosen for the experimental program. It was found that the model is presented for thermal conductivity of porous construction materials that takes in to account the porosity, the conductivity of solid, and the nature of the pore. Geometrical idealization of pores and their synthesis proposed in the model enables the microscopic inclusion of three-dimension heat transfer in the pores maintaining overall one-dimension treatment at the macroscopic level. These values can be used as inputs to the model for predication of thermal conductivity.

Quesada *et al.* [53] investigated the use of different wastes in the manufacture of ceramic bricks such as (urban sewage sludge, bagasse, sludge from the brewing industry, olive mill wastewater and coffee ground). Residues were blended with clay to produce bricks. Amounts of residues were studied (urban sewage sludge 15 mass%, bagasse 2.5 mass%, sludge from the brewing industry 5 mass%, olive mill wastewater 6.5 mass% and coffee ground 3 mass%) by mixed with raw brick-clay. Samples were fired at 950 ^{o}C. It was found that the water absorption increased to above 35% when urban sewage sludge, brewing industry sludge and bagasse were incorporated into the body, but the compressive strength decreased by a maximum of 19% and the thermal insulation increased by at least 8%. The incorporation of coffee grounds and olive wastewater of clay was more beneficial, with compressive strength values similar to bricks without waste and a 19% improvement in thermal conductivity.

Abdul Kadir and Mohajerani [54, 55] investigated the utilization potential of cigarette butts (CBs) in lightweight fired bricks. Four different clay-CB mixes with 0, 2.5, 5.0 and 10.0% by weight CBs, corresponding to about 0, 10, 20 and 30% by volume, were used for making fired bricks samples. Samples were fired at 1050 ^{o}C. The results show that the density of fired bricks was reduced by about 8-30%, depending on the percentage of CBs incorporated into the raw materials. The compressive strength of bricks tested was 12.57, 5.22 and 3.00 MPa for 2.5, 5.0 and 10% CB content respectively. Water absorption and initial rate of absorption values increased as density, and hence porosity, of bricks decreased with increasing CB volume. Thermal conductivity performance of bricks was improved by 51 and 58% and 10% CBs content respectively.

Ajam *et al*. [56] used phosphogypsum (PG) into the fired clay bricks. The PG, which plays the part of a grease-remover, was then introduced at various mass percentages of 0, 5, 15, 25, 30 and 40% by weight as a replacement of sand in brick. Brick were fired at 830 ^{o}C. The obtained results showed that with 30% of PG incorporation, the bricks successfully satisfied the standard requirements. The increase of the percentage of PG resulted in a decrease in the mechanical strength of these mini-bricks, but it is still higher than the standards limits. The 25% ratio of substitution appeared to be the most effective considering the performed tests.

In this study, the additive used is charcoal which is a local material. It was mixed with Hang Dong clay with 3 different sizes and various percentages. In order to find the best qualities of potential clay bricks made from Hang Dong clay mixed with charcoal addition, the test briquettes were fired at different temperatures to be examined for their mechanical and physical properties.