SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

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PRELIMINARY STUDY ON THE FABRICATION AND CHARACTERIZATION OF LIGHTWEIGHT PORCELAIN TILES VIA TRI-LAYER PRESSING METHOD

By

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled "**Preliminary Study on the Fabrication and Characterization of Lightweight Porcelain Tiles via Tri-Layer Pressing Method**". I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or university.

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KAJIAN AWAL FABRIKASI DAN PENCIRIAN JUBIN PORSELIN RINGAN MELALUI KAEDAH PENEKANAN TIGA LAPISAN

ABSTRAK

Tujuan kajian ini dilakukan adalah untuk menghasil dan melakukan pencirian terhadap jubin porselin ringan dengan mengunakan kaedah penekanan tiga lapisan. Jubin porselin ringan terdiri daripada tiga lapisan berbeza dimana lapisan atas dan bawah adalah serbuk porselin komersial manakala lapisan tengah merupakan campuran serbuk porselin komersial dan serbuk kalsium karbonat. Parameter yang dikaji adalah nisbah berat serbuk porselin komersial kepada serbuk kalsium karbonat pada lapisan tengah (100% serbuk porselin komersial, 95% serbuk porselin komersial/5% kalsium carbonate, 90% serbuk porselin komersial/10% serbuk kalsium karbonate dan 85% serbuk porselin komersial/15% serbuk kalsium karbonat) dengan suhu bakar (1050 ^{0}C dan1150 ^{0}C) masing-masing. Campuran serbuk porselin komersial dan serbuk kalsium karbonat ditimbang mengikut nisbah dan pencampuran kering dilakukan menggunakan botol HDPE, penekanan eka paksi (bentuk jubin; panjang: 10cm, lebar: 5cm, tinggi: 0.5cm) diikuti dengan pengeringan selama 24 jam sebelum dibakar. Sampel yang dibakar dicirikan dengan pemerhatian fizikal sampel, pengecutan isipadu, ketumpatan pukal, penyerapan air, modulus kepecahan, pekali pengembangan haba, dan analisis pembelauan sinar-X (XRD) untuk pengenalpastian fasa. Sampel dengan 90 % serbuk porcelain/10 % serbuk kalsium karbonate (T3, T7) yang dibakar pada suhu 1150^{0}C menunjukkan ketumpatan yang paling rendah (2.13 g/cm^3) dan penyerapan air yang paling tinggi (5.56%). Pada suhu bakar 1150^{0}C, ketumpatan jubin dapat dikurangkan sebanyak 1.38% sehingga 2.13% daripadan ketumpatan sampel kawalan (2.18g/cm^3). Bagaimanapun, sampel dengan 85% serbuk porselin komersial/15% serbuk kalsium karbonat (T4, T8)

mengalami masalah penyahlapisan. Keputusan pekali pengembangan termal (CTE) membuktikakan masalah penyahlapisan bukan disebabkan oleh perbezaan pengembangan termal antara lapisan tengah dengan lapisan atas dan bawah.

PRELIMINARY STUDY ON FABRICATION AND CHARACTERIZATION OF LIGHTWEIGHT PORCELAIN TILES VIA TRI-LAYER PRESSING METHOD

ABSTRACT

The aim of this study is to fabricate and characterize lightweight porcelain tiles by tri-layer pressing method. Lightweight porcelain tiles consists of three different layer whereby upper and bottom layer contain commercial porcelain powder and middle layer consists of mixture of commercial porcelain powder and calcium carbonate ($CaCO_3$). Parameters studied in this work were weight ratio commercial porcelain powder/calcium carbonate in the middle layer (0% $CaCO_3$ + 100% porcelain powder, 5% $CaCO_3$/95% porcelain powder, 10% $CaCO_3$/90% porcelain powder and 15% $CaCO_3$/85% porcelain powder) with two firing temperature (1050 ^{0}C and 1150 ^{0}C). The mixture of the commercial porcelain powders and $CaCO_3$ are weight according to the ratio and dry mixed in HDPE bottle, uniaxial pressing (tiles shape; length: 10cm, width: 5cm, height: 0.5cm) followed by drying for 24 hours before firing. Fired samples were characterized by appearance observation, volumetric shrinkage, bulk density, water absorption, modulus of rupture (MOR), coefficient of thermal expansion (CTE) and X-ray Diffraction (XRD) analysis for phase identification. Samples with 90 %Porcelain/10 %$CaCO_3$ (T3, T7) fired at 1150 ^{0}C show lowest density (2.13 g/cm^3) and highest water absorption (5.56%). At 1150 ^{0}C, fired tiles are able to reduce down the density to around 1.38% to 2.13% of the density of control sample (2.18 g/cm^3). However, samples with 15% $CaCO_3$/85% porcelain powder (T4, T8) faced delamination problem. CTE result prove that delamination are not occur due to different in thermal expansion between middle layer with top and bottom layer.

CHAPTER 1

INTRODUCTION

1.1 Background research

Ceramic are generally inorganic material which are made up of compounds formed from metallic and non-metallic elements which are iron, copper, salt, coal and etc. In modern application, definition of ceramic has been change as everything that is not metal or non-organic material (Sharma, 2007). The properties of the ceramic can be obtained through firing process. A variety of raw materials and manufacturing methods used in the ceramic field according to specific application. There are several types of ceramic product in this world: ceramic tiles, structural ceramic, porcelain, earthenware and refractories (Binggeli, 2008). This type of ceramic product are categorized under traditional ceramic. Advanced ceramic processed by the same method but their properties are usually used for high technology application like aircraft, automotive etc. (Saleem Hashmi, 2014). There are some example of advance ceramic which are alumina, aluminum nitride, zirconia, silicon carbide, silicon nitride and titania-based materials, each with their own specific characteristics. Zirconia as example, it has very good properties at higher temperature which are it offers corrosion and chemical resistance at high temperatures up to 2400°C which is above the melting point of Alumina (Brostow & Lobland, 2016).

1.2 Porcelain

` Typical porcelains composition consists of kaolin [$Al_2Si_2O_5(OH)$], silica (SiO_2), feldspar [$KAlSi_3O_8$ – $NaAlSi_3O_8$ – $CaAl_2Si_2O_8$] and ball clay. In porcelain composition, clay provide function as to serve a good plasticity for forming. Good plasticity will increase the workability and high dry strength of ceramic body. However, good plasticity also will introduce high shrinkage to the ceramic body. In the porcelain composition, there are also impurities which will influent the colour of the ceramic body after firing (Rhodes, 2015). Feldspar serves as a flux, it will produce a viscous liquid when fired at higher temperature and it will also assist in vitrification. A sufficient quantity of feldspar is needed in the composition as to acquire the required glassy phase. The quartz acts as at filler material which remains unreactive at low temperatures of firing and forms a highly viscous liquid at higher temperatures. Besides that, the presence of quartz is also important because presence of quartz is necessary to be able to decrease shrinkage (Kitouni & Harabi, 2011).

1.3 Porcelain Tiles

Porcelain tiles could be characterized with their important characteristic which are high density (2380–2450 kg/m^3), have very low water absorption (<0.5%), and limited porosity with small pore size (<50 μm) (García-Ten, Saburit, Bernardo, & Colombo, 2012). This statement is in reasonably agreement to their characteristic which have high mechanical strength. They have very low water absorption due to the fact that they are sinter to a very high temperature around 1200°C which may cause them to become very tough and dense (García-Ten, Saburit, Bernardo, & Colombo, 2012). This type of tile has been widely used as wall and floor and in ventilated facades. A ventilated exterior is a cladding framework with an air pad or cavity promptly behind which furnishes with a seepage, ventilation and thermal solution. In recent years, the demand for porcelain tile has grown significantly compared to that of other ceramic construction materials, growth being particularly attributed to porcelain tile's enhanced performance characteristics, especially regarding water absorption, frost resistance, bending strength, and wear resistance (Alvaro Guzman et al, 2016)

1.4 Lightweight tile

Wall and floor tiles have been used since long time ago. They have several properties which make them very high demand such as they are easy to clean, water resistant, hygiene and very attractive. However, lately, porcelain tile applications have spread to other application which could increase demanding of used porcelain tiles. One disadvantage for some of these new applications is the porcelain tile is very heavy, which can make it difficult to handle and install. Besides that, more problem will arise such as raises transport and distribution costs. The reduction of porcelain tile weight could enhance the use of this product in new areas and improve at the same time other properties, such as thermal and acoustic insulation. There are some work being reported in fabrication of lightweight tiles. (Novais, Seabra, & Labrincha, 2015a) had reported the production process of bi-layered porcelain stoneware tiles, formed from two layers with different densities – dense and porous – and with adjustable thickness. The novel production method comprises a double pressing action that ensures the development of a perfect interface bonding between layers

One of the most popular method to promote lightweight tiles is by introducing the porous structure inside the tiles. The porous structure could be introduce inside the tiles by using pore forming agent that mixed with the ceramic tiles composition. This pore forming agent will decompose after firing at high temperature and it will generate pore inside the tiles body. There are also another method such as partial sintering, by using polymeric foam templates, ceramic hollow spheres or sacrificial pore-forming agents (Novais et al., 2015a).

1.5 Problem statement

Guocera Tile Industries (Meru) Sdn. Bhd. had produce about 12,000 to 15,000 tiles per day. All types of tiles produce will be distributed to the supplier before being sold to consumers. Conventional ceramic tiles use more energy and fuel to transport from one place to another place due to the fact that this conventional ceramic tiles is heavier. Thus this excessive use of fuel not only increases the budget but also emits more pollutants to the environment (Mostofa Kamal Nasir et al, 2014). Nowadays energy saving had become the most important issue due to recent increases in fuel prices have given a great impact on global economic changes**.** The fact is that these increases cannot be avoided because the price of fuel is rising in the international market (Sorrell, 2015). Besides that, heavy tiles also will introduce more stress on a building's structure due to the fact that commercial ceramic tiles are heavy. This will lead to the building that will not survive long period of time. Therefore, Guocera Tile Industries (Meru) Sdn. Bhd. have try to reduce the weight of the tile as well as maintaining the properties of the tiles. Hence, the development of lightweight tiles is conducted to keep down fuel consumption as well as reduce the stress on a building's structure.

In previous studies, Cetin et al., (2015) investigated effect of adding mining tailing such as boron waste residue, basalt rock and soda lime cullet to produce lightweight tiles. The method involved a double pressing action. The first layer with a square die (50mm x 50mm x 5mm) were pressed at 10MPa and the second layer which is the mixture of ceramic raw material and mining tailings were press at 30 MPa. They concluded that the waste can effectively reduce the density while maintaining the water absorption below 2%.

In other research, Rui M. Novais et al., (2014) investigate the development of bi-layered ceramics tiles, which is formed from two layers with different densities. One of the layer is highly dense while another layer is highly porous. The method involved is double pressing action. In this research, they had use polypropylene (PP) and polymethyl methacrylate (PMMA) as the pore forming agent to create the porosity. They had concluded that by adding the pore forming agent it can result in weight reduction (up to 12.5%) while suitable mechanical properties can be maintain. They also investigate the effect of adding wood waste as the pore forming agent. The results demonstrate that sawdust can be incorporated into the raw material and it will reduces product weight (up to 7.5%), while maintaining suitable mechanical resistance in comparison to commercial stoneware tiles.

García-Ten et al., (2012) investigate the possibility to fabricate the lightweight tiles by incorporation of Silicon Carbide (SiC) to the porcelain stoneware tiles. The study was conducted with an industrial spray-dried powder customarily used to manufacture porcelain tiles (STD), obtained from kaolinitic–illitic clays, quartz, and sodium feldspar. In their research, they have proved that the addition of foaming agent in their case they use SiC powder with a size < 10 μm will produce the tiles with a suitable strength, negligible water absorption and can reduce the weight by 26%.

Enrico Bernardo et al., (2010) investigate the addition of the Cerium (IV) oxide (CeO_2) to the raw materials. The addition of CeO_2 provides some porosity due to the evolution of oxygen. The result demonstrate the achievement of a reduction in density of about 30%, coupled to a limited water absorption (about 2%).

The research about the fabrication of lightweight tiles is not new. Despite that, there is still lack of findings the suitable raw material and method as to fabricate the lightweight tiles. A new focus is set to fabricate the lightweight porcelain tiles by tri-layer method with triple pressing approach instead of the bi layered ceramic tiles that reported by Rui M. Novais et al., (2014). Tri-layer pressing method will give suitable mechanical strength while the introduction of the porosity is by means of incorporation calcium carbonate as pore forming agent to the porcelain composition to promote the weight reduction. Selection of calcium carbonate instead of other raw material such as mining tailing as reported by Cetin et al., (2015). This is because mining tailing is a waste. Usually, the composition of the waste vary according to the batch. Hence, inconsistency of the composition will affect the properties of lightweight tiles produce. Raw material used in this study are commercial porcelain powder which is prepared by Guocera Tile Industries (Meru) Sdn. Bhd and pore forming agent used in this study is calcium carbonate ($CaCO_3$). Lightweight porcelain tiles were produced by a tri-layer pressing technique at room temperature. It is formed by an upper and bottom layer with density similar to a conventional porcelain stoneware tile serve to maintain the mechanical strength, and a porous middle layer, which promotes weight reduction of the product.

1.6 Objective

The objectives of this studies are as follows:

1. To investigate the feasibility of triple pressing method for fabrication of lightweight porcelain tiles by using commercial porcelain powder as starting materials
2. To investigate the effect of different amount of calcium carbonate and different firing temperature on the properties of lightweight porcelain tiles.

1.7 Scope of research

In order to accomplish the objectives mentioned in section 1.5, experimental work of this research is divided into three stages as shown in Figure 1.2.

Stage I is the characterization of the raw material. This stage involved with the preparation and characterization of raw material. The raw materials are validated by performing several characterization testing such as X-ray Diffraction (XRD) for phase analysis, X-ray Fluorescence (XRF) for elemental analysis, Thermogravimetry (TG) and differential thermal analysis (DTA), Particle Size Analysis and Scanning Electron Microscope (SEM) for morphology of raw material.

Stage II is the fabrication of lightweight tiles. The tiles consist of three different layer whereby the upper and bottom layer is comprise with commercial porcelain powder and middle layer is the mixture of commercial porcelain powder and calcium carbonate. Top and bottom layer has weight ratio 35% of powder, while middle layer has weight ratio 30% include the amount of the Calcium Carbonate (0%, 5%, 10%, and 15%) of the middle layer as illustrated in figure 1.1 followed by pressing into tiles and subsequently fired at its respective firing temperatures. The composition of the porcelain + calcium carbonate used in this research are 100 %porcelain, 95 %porcelain/5 %calcium carbonate, 90 %porcelain/10 %calcium carbonate, and 85 %porcelain/15 %calcium carbonate. The firing temperature used have been set at temperature 1050^{0}C and 1150 ^{0}C,

Stage III is the characterization of tiles in terms of physical properties (visual inspection, percentage of shrinkage, bulk density, and water absorption), mechanical properties (modulus of rupture), microstructural examination, coefficient of thermal expansion and changes in phase composition of lightweight tiles by XRD phase analysis.

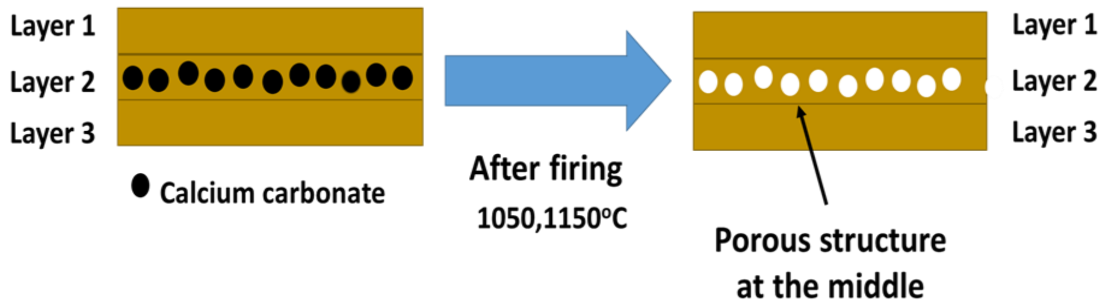

Figure 1.1: Illustration of tri-layer pressing approach

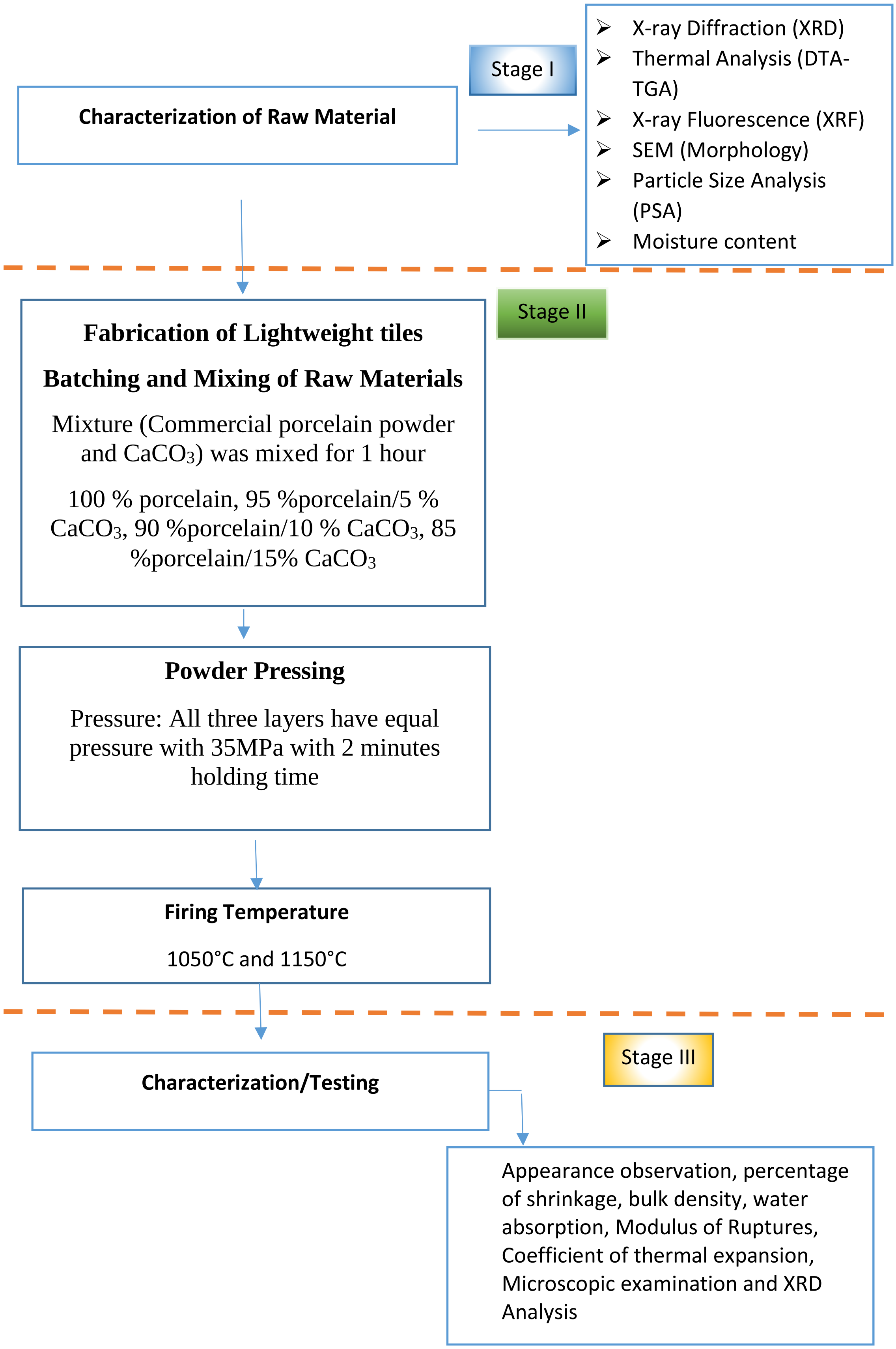

Figure 1.2: Flowchart of the Preliminary study on the fabrication and characterization of lightweight porcelain tiles by tri-layer pressing method.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Ceramic Materials

Ceramic has very wide range of material and possesses very wide application because of its have several properties which will certainly make them suitable to many application. Some of the properties of the ceramic are high hardness, ability to resist heat and corrosion. Ceramics are classified as inorganic solid and non-metallic materials which will held together by combination of mixture of ionic and covalent bond. They are most frequently oxides, nitrides, and carbides (Yacobi et al., 1990).

Ceramic can be divided into two type which are traditional ceramic and advanced ceramic. Traditional ceramic were produce from naturally occurring raw materials. Traditional ceramic usually have been produce by using a suitable amount of clay. Clay will provide sufficient amount of plasticity when mix with water, and this plasticity will make the clay body easier to be shape and reproducibility.(Kasrani et al., 2016). On the other hand, advanced ceramics can be differentiate from traditional ceramic in term of the raw material. The raw material for advance ceramic are produce from high-purity ceramic powders, and their properties could be manipulated by varying the procedure parameter of the raw material, and the processing itself. (Basu et al.,2011).

Ceramic raw materials are generally classified with their functions in ceramic manufacture in addition to their basic properties. Generally, the raw material for ceramic manufacture can be divided into two type which is plastic material and non-plastic material. Ball clay, China clay, feldspar, silica, dolomite, talc, calcite and nepheline are the common raw materials used for most of the traditional ceramic products. These material are generally low cost. Every raw material has their own function and this function will contribute to the ceramic body. Clay is the main raw material for traditional ceramic and it will provide the plasticity. Plasticity is obtained when clay mix with water, once mix with the water, clay will developed plasticity and can be shaped easily. The function of quartz is used to reduce the tendency of a ceramic body to wrap or distort when fired forming an amount of liquid phase in the body. Feldspar act as a fluxing agent to the ceramic body. It will reduce the firing temperature of the ceramic body. (A. Piestrzynski, 2001).

2.2 Ceramic tiles

Ceramic tiles have traditionally been used as wall cladding and flooring material, because of their technical characteristic, but also due to their aesthetical value. Their technical characteristic is dependent on their application. As example, for the earthenware usually used for wall cladding has high porosity with high moisture absorption (10-18%). For stoneware, their application usually for flooring has low porosity with low water absorption less than 3%. In recent decades, they have been new development a new group of tiles known as porcelain tiles. This porcelain tiles has very low porosity and low moisture absorption which can be less than 0.5%. (Saleem Hashmi, 2014). Table 2.1 shows the example of traditional ceramic.

Table 2.1: Example of traditional ceramic (Werner Martienssen, Hans Warlimont, 2005)

Type	Properties	Application
Fired Brick	• Porosity 15-30% • Firing temperature 950-1050^{O}C	Brick, pipes, walls, floor tiles
China	• Porosity 10-15% • Firing temperature 950-1200^{O}C	Sanitary, tiles
Stoneware	• Porosity 0.5-3% • Firing temperature 1100-1300^{O}C	Crucibles, lab ware
Porcelain	• Porosity 0-2% • Firing temperature 1100-1400^{O}C	Insulators, Lab ware, cookware

2.2.1 Properties of ceramic tiles

Ceramic generally have specific properties associated with them which can make them very useful in our daily life.

2.2.1.1 Brittleness

Ceramic tiles are brittle because they have low tensile strength. This reason that ceramic tile are brittle is due to the fact that ceramic are contain mixture of ionic-covalent bonding which can hold the atom together (Carter, 2013). Both bond will restricted dislocation motion and slip. So, this is one of the reason that ceramic tiles is brittle which is the ceramic tiles are difficult to slip. Because of this also the strength of the ceramic tiles is said to be higher compare to other material (Campbell, 2012). The brittleness of the ceramic tiles will make them difficult to be bend after forming and lack of this ductility will become the main shortage to ceramic tiles (Yglesias, 2014).

2.2.1.2 Compressive strength

Ceramic are stronger in the action of compression compare to the tension, otherwise metal are stronger in tension. This is the reason why many ceramic material have been used in load bearing application. Ceramic also have very low degree of toughness. But, this can be overcome by combining the ceramic properties with other material properties to produce composite material (Carter, 2013).

2.2.1.3 Chemical insensitivity

Ceramic are stable and inert to chemical and thermal environment. Many ceramic are inert to thermal environment which means it stable at higher temperature. Chemical insensitivity will allow the surface of ceramic tiles to prevent the dust accumulation. Besides that, ceramic tiles will also do not absorb water, any chemical. This will make ceramic tiles suitable for many application such as wall tile and floor tiles (Yglesias, 2014).

2.2.1.4 Water absorption

Ceramic tiles are often categorize by the water absorption. Water absorption can offer the indicator to generalize their used and their limitation. Water absorption could be a characteristic that shows the amount of tile porosity. Bigger water absorption means that bigger porosity and therefore the opposite, less absorption means the structure is more compact. ANSI A137 list out four classification of the water absorption. (Postell, 2011).

1. Nonvitrous tiles usually have more than 7 percent of water absorption
2. Semivitrious tiles have water absorption between 3-7 percent
3. Vitreous tiles have water absorption between 0.5 – 3 percent.
4. Impervious tiles have water absorption less than 0.5 percent.

The tile's performance is great if the water absorption rate is low regarding mechanical quality and ice resistance.

2.2.1.5 Abrasion resistance

Abrasion resistance is the ability of surface of tile to resist to the wear cause by human's foot or equipment. The wear action is related to the materials that carried on the surface of tile such as water, sand mud and etc. (Byrne, M., 2008). Ceramic tile has excellent abrasion resistance due to their hardness. Once the hardness of a material is higher than it mating surface, it can promote wear resistance (Basu, 2011).

2.2.1.6 Breaking strength

Ceramic tiles used in application whether wall or floor tile must be able to support expected load. So as to decide the breaking strength of the ceramic tiles, force is apply to the ceramic tiles until it achieve moment that breakage happen. Final selection of the tiles is based on the breaking strength value (M L Gambhir, 2014). Breakage will happens when the bond between particle crack along a plane and split separated on a plane opposite to the tensile strength (Somiya, 2012).

2.2.2 Ceramic Tiles Processing Routes

Ceramic tiles processing routes can be divided into several step starting from raw material until finish of firing process.

2.2.2.1 Raw material

Ceramic raw material generally can be split into two group which are plastic and non-plastic raw material. Plastic raw material could be defined as any raw material when mix with water, it will produce plastic properties. Plasticity can be defined as the capability of the clay to be deformed without rupture when mix with water and aid by sufficient quantity of force and once the external force is remove the shape is maintain. Plasticity in the processing parameter is important because it is a necessary parameter that will determine the ability of the ceramic body to convert from ceramic composition to its body component. (Andrade et al., 2010). Compare to non-plastic material, when mix with water, it will not reveal the properties of plasticity. Although, they do not have the role of the plasticity, they have their own function in the ceramic body system. Some of non-plastic ceramic raw materials will acts as a filler, reducing high plasticity or shrinkage of the body when drying or firing. Besides that, other non-plastic raw materials are used for sintering, fluxing and melting or to increase the refractoriness (Konta, J, 1980).

Usually for porcelain tiles, they were formulated from a kaolin–quartz–feldspar system (De Noni et al., 2011). The function of kaolin is to gives plasticity and binding characteristics to the mass, enhances mechanical characteristic in the fired tiles, produces good rheological flow properties and gives a good density level during firing due to the individual characteristic of the clays (Andrade et al., 2011).

The function of feldspar to develop a glassy phase at firing temperature and lower the firing temperature thus it can reduce the cost. Besides acting as a flux, feldspars also ease the process of drying and it also will release of gas during firing.(Martín-Márquez et al., 2010).

Addition of silica sand decreases its unfired strength and plasticity but assist to facilitate escape of gases during drying and firing. Silica usually used in the ceramic body composition due to the energy need to crush the silica is low. It also reduces drying shrinkage and increases the whiteness of the fired body. Quartz also play important role in contraction. They will reduce the tendency of the ceramic body to wrap or distort due to present of a lot amount of viscous glass (Dana et al., 2004). The contraction of individual quartz grains may lead to thermal cracking and opening of grain boundaries. Ceramic body that contain moderate to large amount of quart will fracture during thermal cycling through transformation temperature. During heating, when reach 573^oC, there will be transformation of the β-Quartz to α-Quartz. The transformation will induces residual stress thus will circumferential cracking around quartz particle. This also happen during cooling and can lead to cracking of ceramic ware if cooling occurs too quickly through the inversion temperature (Mark J. Jackson, 2005).

2.2.2.2 Batching

The preparation of the body begins with proportioning or batching of the various raw materials in the correct amounts. The mixing of the body from individual components follows the coarse-crushing of the raw materials and is carried out according to the body formulation. The common formulation raw materials used to produce tile consist of kaolin (50%), feldspar (25%) and quartz (25%) (De Noni et al., 2011). This common formulation is known as triaxial porcelain. Triaxial porcelain is one of the most widely studied ceramic systems. This system can be used in many application such as stoneware, whiteware, insulators (Correia *et al.*, 2006).

2.2.2.3 Mixing and Milling

Mixing is done to produce homogenous mixture of two or more than component. Mixing can be divide in two method which are wet and dry method. Dry mixing is done to obtain as much as possible the homogeneous of the mixture of the powder. The purpose of grinding is to obtain smaller particles out of coarser size as well as to achieve suitable size distribution of materials so that they can pack and give maximize packing density. Usually dry mixing is simultaneously done with the grinding in order to get homogeneous mixture as well as fine particle size of the powder (Ghorra, G, 1987).

2.2.2.4 Forming

There are several methods used for making ceramic tiles: extrusion; compaction or pressing. But, most of the ceramic tiles are formed by dry pressing. The purpose of the pressing stage is to shape the powder into a compacted piece of unfired tile. Basically, it involved by filling up suitable amount of the powder into the mould, and by the action of the force, the compaction will occur and the tiles is produce. In pressing stage, particle size and moisture content need to be control because it will influent the packaging of the powder during pressing. The highest packaging of the powder is required to achieve high density tile as well as to reduce the porosity (Acchar and J. V. Dultra, 2015).

There are two types of presses namely the hydraulic press and friction press. The most commonly used presses in the ceramic tile industry are the hydraulic presses. In the production of porcelain tiles, hydraulic press with the capacity of the 2000 tons with four cavities are use. According to Biffi (2002), the compression pressure for the production of porcelain tiles must be between 350 and 450 kg/cm2. In this range, the density of particles can be control. It will make easier to release organic substances and removal of gases that are generated. If the compaction pressures higher than 500 kg/cm2, in some cases, can cause internal defects and thus increased porosity of the fired body. The powder is compressed in a steel cavity by steel plungers and is then ejected by the bottom plunger. Automated presses are used with operating pressures as high as 2500 tons.

2.2.2.5 Drying

Drying of the ceramic tile is carried out between the pressing stage and the firing process. This is carried out to increase the strength of the unfired tile and also to reduce the risk of tile loss due to deformation as the tile rapidly shrinks or cracks as the steam is rapidly evolved in the kiln. Besides that, the purpose of drying is to remove any water present in the tiles. This water will leave pores, crack after firing complete thus it will reduce the strength of the tiles. Usually the drying process done in the kiln at the temperature 100°C to 200°C for one or two days (Acchar and J. V. Dultra, 2015).

Usually in the green body, there will be entrapped water inside it. The 5-6% residual moisture in the green body must be remove before undergoes firing stage. This must be done to prevent the tile from exploding due to sudden formation of steam inside the green body. Drying process can be done by two method: vertical or horizontal method. Frequently, horizontal method is use compare to vertical method. This is due to when using horizontal method, it will required less handling of the green tile and it will produce less breakage and less chipping (Ciullo, 1996).

2.2.2.6 Firing

Firing is the final stage in the ceramic tile manufacturing. At this stage, unfired tiles is transformed into a strong, durable product due to the effect of chemical and physical reactions within the green body during heating (Manfredini T et al., 1996). After firing, the ceramic tile body adopts the mechanical and aesthetic properties of the finished ceramic piece. During firing, the vitrification phenomena would happen. Vitrification phenomena happen through the formation of the liquid phase. This liquid phase will flow and fill up the pores inside the structure. When cooling, this liquid phase will transform to the glassy phase and promote dense and durable tiles body. The vitrification depend on the temperature and cooking time. Flux such as feldspar are added in order to reduce the temperature for the liquid to form. During firing, as the temperature increase, ceramic body will contract. This contraction will reduce the porosity inside the ceramic body. The reduction in the porosity will make the ceramic body dense. As the amount of porosity tend to decrease, the shape of pores become more spherical shape. (Acchar and J. V. Dultra, 2015).

2.3 Types of Tiles

Tiles are thin plates that used to cover building surface such as roof, wall or floor. These tiles are made from clay and other inorganic compound. These tiles can be split into two groups which are porcelain tiles and non-porcelain tiles. The porcelain tile is a clay body composition with the conventional triaxial kaolin-feldspar-quartz components (Correia *et al.*, 2006). Porcelain tiles is different from other ceramic tiles in term of raw material, manufacturing. The different in manufacturing make porcelain tiles more durable, high density as well as low water absorption (García-Ten et al., 2012).

2.3.1 Porcelain Tiles

Porcelain tiles is produce by pressing at high pressure until 40MPa and fired at temperature 1200^{O}C. The higher firing temperature will make them very tough and dense compare to ceramic tiles. Usually porcelain tiles can be characterise by low water absorption less than 0.5%. (M L Gambhir, 2014).

Porcelain tile is a vitrified product of mixtures of kaolin, quartz and feldspar. Feldspar are used as fluxes to form glassy phase in body and promote vitrification and translucency. Silica, SiO_2 occurs in nature as dense rock quartzite and as silica sand. Sand is preferred raw material in ceramic industry due to it don't need high energy to crush it. Besides that, silica sand is the most abundance mineral on the earth. Quartz is acts as filler and the function of quartz (SiO2) to maintain the shape of the formed article during sintering. They will reduce the tendency of the body to wrap or distort (Mwakali, J. 2006).

2.3.2 Glass tiles

Glass tiles are fabricated by inserting the glass into the mould. Glass tiles can be divided into two type which are clear glass and translucent glass. Glass tiles have very unique characteristic which is inert to many chemical and can be easily clean by using cleaning agent. Glass tiles also have properties which is can change in dimension if threated with the change in temperature. Therefore, the used of glass tiles around the fireplaces should be carefully evaluated. Compared to other types of tiles, glass tiles is brittle compared to other tiles body (Godsey, 2012).

2.3.3 Glazed Tiles

Glazed tiles have surface characteristic similar to glass tiles. They have characteristic such as impervious to water and staining but they also have lack of strength in term of chipping and scratching. Glossy finished is not suitable to be used as floor tile because the scratch clearly can be seen and the surface of the tiles is slippery and become danger to the consumer. There are several type of glazed which are clear glaze (transparent or without colour), matte glaze (low-gloss glaze), opaque glaze (non-transparent coating) and semi-matte glaze (medium-gloss finish)(Godsey, 2012).

2.3.4 Unglazed tiles

Unglazed tiles is the type of the tiles that are the most durable. Unglazed tiles are tiles which are coated with the glazed. This will make the unglazed tiles exposed to the staining due to the porosity present in the tiles body (Binggeli, 2008).

2.4 Application of Tiles

2.4.1 Wall tiles

Wall tiles is one example of the glazed tiles. It has relatively high water absorption with low mechanical strength. The water absorption for wall tiles is higher than 10% (>10%) (Doran, 2013). The process of making wall tiles include tunnel kiln (14 hours cycle) or fast fire roller hearth kiln (40 to 60 minutes kiln) (Ciullo, 1996).

2.4.2 Floor tiles

Floor tiles can be characterize with low water absorption with high mechanical strength. This characteristic is based on the criteria need for the floor tiles. The water absorption for floor tiles is as low as less than 3% (Doran, 2013).

2.5 Lightweight tile

Naturally, ceramic material has its own pores. This occurs from the raw material itself due to the compaction of the powder and from the water entrapped in the ceramic body. When this ceramic body undergoes drying and firing, this entrapped water will vaporised and leave pore in the ceramic body. This natural porosity is insufficient for application situations where it is important to assure a good thermal and electrical insulation, in addition to refractory properties, and where a reduced weight is required. (Mueller-Zell, 2013).

Lightweight tile promote the weight reduction of the tile compare to the fully dense body tile due to the present of the porous structure inside the porcelain tile. The present of porous structure is due to the incorporation of pore forming agent (porogen) inside the porcelain tile. This lightweight tile can give several advantage to the industry in term of cost of distribution and transportation**.** (Novais et al., 2015a)

Prior to forming, pore forming agent are commonly mixed with the ceramic raw material. The concept involved is that organic particles are burnt out during heating to the firing temperature. Thus leaving pores in the ceramic body which correspond to the space originally occupied by the pore forming agent particles. The size and morphology of these voids can be control by choosing the suitable amount of pore forming agent and particle size distribution. The obtained porous ceramics, having reduced density and weight, are commonly used in a wide range of applications, such as tableware, sanitary ware, tiles, insulators, and various building and construction materials. The main criteria of the selection of the pore forming agent which are non-harmful thermal decomposition during firing, environmental friendly.

The mechanical strength of the ceramic body is related to the density of the ceramic body. The higher the density of the ceramic body, the stronger the ceramic body. (Huang et al., 2011). Generally, the introduction of the porous structure will give benefit in term of the thermal and electrical insulation as well as it will reduce the density and weight of the ceramic body. But, there are also negative effect such as it will reduce the strength of the ceramic body. Dramatic reduction of modulus of rupture can be experienced when high levels of porosity are introduced in the ceramic, and in particular open porosity.(Rakhit, 2013).

Moreover, by introduce the porous structure to the ceramic body, it can been seen that water absorption will increase which is undesired for the ceramic industry. However, the reduction in the strength of the ceramic body can be overcome by controlling the homogeneity of the pore distribution.(West, 1996).

2.6 Design of porous ceramic

Many different technique has been used in order to develop the porous structure. The processes for manufacturing porous ceramics can be classified into three categories, which is replica techniques, sacrificial template and direct foaming (Studart et al., 2006). Sometimes pore forming agent selection may have some negative effect to the ceramic body like improper selection, thus trial and error experiments are needed.

2.6.1 Mechanism of Replica technique

Replica technique systems include the impregnation of a cell structure with ceramic suspension or precursor solution to create a macroporous fired showing a comparative morphology to the original version. Many synthetic and natural cellular structures can be used as templates to fabricate macroporous ceramics through the replica technique. Some of them are (a) synthetic templates and (b) natural templates. In synthetic templates, it involves ceramic suspension that was soaked with highly porous polymeric sponge into until the internal pores are filled in with ceramic material. Then the excess suspension was remove by mean the action of force by roller. It will enable the formation of ceramic coating over the structure of the original polymeric sponge. Ceramic suspensions should have shear-thinning behaviour to efficiently coat the polymeric template. The ceramic-coated polymeric template is subsequently dried and pyrolysis through careful heating between 300^{o}C and 800^{o}C. Heating rates usually lower than 1^{o}C/min are required in this step to allow for the gradual decomposition and diffusion of the polymeric material, avoiding the build-up of pressure within the coated structures (Studart et al., 2006).

2.6.2 Mechanism of Sacrificial pore former

The sacrificial pore former sometimes consists of the preparation of a biphasic composite. This biphasic composite will contain continuous matrix of ceramic particles and dispersed phase usually known as pore forming agent. This biphasic composite mechanically mix to obtain homogenized and the dispersed phase will be extracted to generate pore inside the ceramic body (Studart et al., 2006). The extraction of the dispersed phase is by mean the action of heat through decomposition of the pore forming agent during firing or sintering. During sintering at higher temperature, this pore forming agent will decompose and it will leave pore inside the ceramic body. Depending on the nature of pore forming agent and it compatibility with ceramic body, ceramic body will have pore structure, pore distribution and pore size. The use of sacrificial microspheres has been shown to give better microstructural control (homogeneous pore distribution)