ASSESSMENT ON PRODUCTION QUALITY OF TRADITIONAL SINGGORA TILES IN MALAYSIA

NOR HIDAYAH BT ABDULLAH

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ABSTRACT

Most users, including the conservators, have no confidence in using Singgora roofing tiles due to their low quality. This phenomenon has caused the Singgora tile industry to become declined and most of the new generation are not aware of the existence of this traditional craft in Malaysia. Based on the comments that often arise regarding this handmade tile, this study was carried out with the aim to improve the quality of Singgora tiles based on the traditional manufacturing method by the local factory in Kelantan.

The methodology that used for this research was case study and experimental works. The data in the case study was collected by observing the manufacturing process in the factory in order to identify the factors that affect the quality of Singgora tiles. Besides, the experimental works was conducted to measure the properties of existing factory product and to investigate the effect of firing condition and impurities on the properties of Singgora tiles. For existing factory product, the tests conducted were the surface quality, dimensional accuracy, percentage and types of impurities, grade of sand in Bris clay, water absorption and flexural strength test while the tiles that fired at various conditions in the laboratory were subjected to water absorption and flexural strength test.

The study found that the quality of existing factory product is low due to the poor quality control in all stages of production. The results of experimental works for samples fired at varying firing temperature and time show the quality of Singgora tiles is significantly improved by firing at higher temperature and longer duration. In addition, the effect of impurities in the untreated clay is decreased and the reliability of the product is increased with the increased of firing temperature and firing time. It was

concluded that the optimum mechanical strength for Singgora tiles within the temperature range considered is obtained at 1050ºC for 4 hours or 900ºC for 6 hours.

Based on the finding of this research, it is suggests that the manufacturing process of Singgora tiles is conducts under quality control. It is important in producing greater surface quality of Singgora tiles with uniform size of product. Besides, the strength of Singgora tiles can be improved by prolongs the timing of firing process using traditional kiln in the factory.

ABSTRAK

Kebanyakan pengguna, termasuk konservator tidak yakin menggunakan atap genting Singgora kerana kualitinya yang rendah. Fenomena ini menyebabkan industri genting ini semakin merosot malah kebanyakan generasi baru tidak mengetahui tentang kewujudan produk ini di Malaysia. Berdasarkan kepada komen yang sering diperkatakan terhadap produk buatan tangan ini, kajian ini dijalankan untuk meningkatkan kualiti genting Singgora berasaskan kaedah pembuatan tradisional oleh kilang tempatan yang terletak di Kelantan.

Metodologi yang digunakan di dalam kajian ini adalah kajian kes dan kerja-kerja eksperimental. Data di dalam kajian kes dikumpulkan melalui pemerhatian terhadap proses pembuatan di kilang untuk mengenalpasti faktor-faktor yang mempengaruhi kualiti genting Singgora. Di samping itu, kerja-kerja eksperimental dijalankan di makmal untuk mengukur sifat-sifat produk kilang yang sedia ada dan mengkaji kesan keadaaan pembakaran dan bendasing terhadap sifat-sifat genting. Untuk produk kilang sedia ada, ujian makmal yang dijalankan adalah kualiti permukaan, ketepatan dimensi, peratusan dan jenis bendasing, gred pasir yang terkandung di dalam tanah liat Bris, penyerapan air serta ujian kekuatan lenturan manakala genting yang dibakar pada pelbagai keadaan di makmal dikenakan ujian penyerapan air dan kekuatan lenturan.

Kajian mendapati kualiti produk yang dibuat di kilang sedia ada adalah rendah disebabkan oleh kawalan kualiti yang lemah di semua peringkat pengeluaran. Keputusan kerja-kerja eksperimental menunjukkan kualiti genting Singgora meningkat dengan ketara apabila dibakar pada suhu yang lebih tinggi dan tempoh yang lebih lama. Selain itu, kesan bendasing yang terkandung di dalam tanah liat yang tidak dirawat berkurang dan kebolehpercayaan produk meningkat dengan peningkatan suhu dan masa pembakaran. Di samping itu, kajian turut mendapati kekuatan mekanikal optimum

genting Singgora yang dibakar pada suhu dan masa yang berlainan telah dicapai pada suhu 1050 ºC selama 4 jam atau 900 ºC selama 6 jam.

Berdasarkan kepada hasil kajian, adalah dicadangkan agar proses pembuatan genting Singgora, bermula dari bahan mentah hingga produk akhir, dikendalikan di bawah kawalan kualiti. Ini adalah penting untuk menghasilkan kualiti permukaan genting Singgora yang lebih baik disamping saiz produk yang seragam. Selain itu, kekuatan genting Singgora boleh ditingkatkan dengan memanjangkan masa pembakaran menggunakan tanur tadisional di kilang.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Singgora tiles are used as an architectural feature for traditional buildings in Kelantan and Terengganu, Malaysia. The quality of these tiles has deteriorated markedly over the last decade. Most of the users, including the conservators, have to face the high cost of maintenance in replacing the broken Singgora tiles. This phenomenon has caused a consequential decline in demand for Singgora tiles. This study is undertaken to improve the quality of Singgora tiles to overcome their deterioration in quality. The methodology used in this research is case study and experimental works. The case study is conducted to identify the factors that affect the quality of Singgora tiles produced by local factory, while the experimental works are carried out to investigate the properties of existing factory product and the effect of impurities and firing condition on the properties of Singgora tiles.

This chapter presents the background studies which include the significance to preserve the industry of Singgora tiles and problems in using this tile for repairing and maintaining the heritage buildings. The chapter also describes the research questions, aim and objectives of the study. In addition, it also presents the scope of research and research methodology. Finally, the research contribution and structure of dissertation are presented at the end of the chapter.

1.2 Research Background

Guidelines by National Heritage Department (2012) stated that all heritage buildings should be conserved and restored to their original construction methods and materials. Maintaining the authenticity of material is vital to preserve the historical value of the building because the original material will reflect the history and identity of the communities within these areas.

One of the original materials for traditional building is Singgora tiles which have been used as roof coverings. Examples of building conservation that used Singgora tiles for roof are Mulong Mosque and Kampung Laut Mosque which located in Kelantan. These buildings are listed as Heritage Register by National Heritage Department. Lim (1987) notes the roof and wall panel of traditional buildings in Kelantan and Terengganu are almost similar with architecture of Thailand. Figure 1.1a and 1.1b are respectively showed a Singgora tile produced in Malaysia and Thailand. Both of these tiles have similar format of installation, which hung on the horizontal tiling battens. This type of flat clay tiles is known as Bullnose tiles, and the shaped of both tiles are slightly different, which Singgora tile in Malaysia is diamond shape while the tiles in Thailand has the shape of pointed arc (Schunck, 2003).

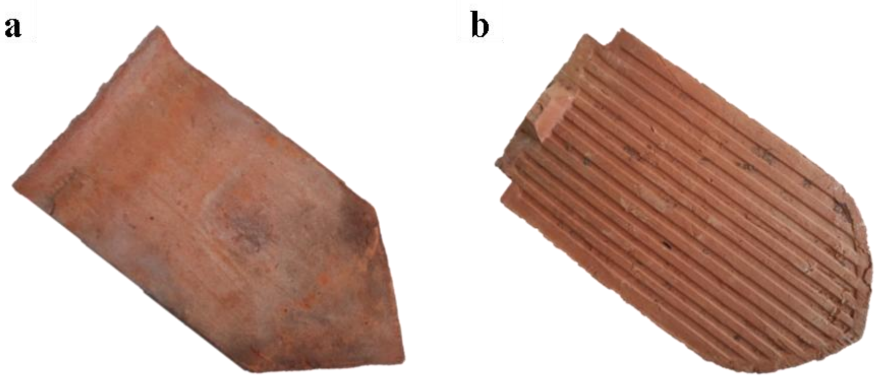

Figure 1.1: Singgora tiles made in Malaysia (a) and Thailand (b)
Source: Field study (2013)

Singgora tiles are the traditional roof covering for traditional buildings in the East Coast of Malay Peninsula. This roofing is commonly found in old buildings which indicate its dominant use before the emergence of modern roofs in 1960 (Adit, 1994). Singgora tiles are produced from clay which is manually moulded and then burnt in a kiln. This handmade tile is traditionally manufactured where its surface is more textured whilst the size and colour varies and are non-uniform. In many circumstances, the colour of tile is pale orange which imparts the natural hue to the building. In terms of aesthetic value, Singgora tiles form a unique look, like fish scales, when arranged in the roof framework (Killmann, Sickinger & Thong, 1994). Zulkifli (1996) reports that Singgora tiles are used traditionally in dwellings, palaces and community centres and it can last for up to 150 years. One of the examples is *Istana Jahar* in Kelantan which was built in 1887 (Nasir, 1979).

Singgora tile is considered as a sustainable product as it is made from clay. According to Costa and Mauroof (2005), the clay tile has the thermal mass characteristic to help the building to cope with the temperature variations throughout the day. During peak temperature, the tiles will absorb the heat, thus provide a cool indoor temperature to the living space. This keeps the interior of the room comfortable during peak temperature hours. At night, the absorbed heat is released, keeping the room to stay warm. Therefore, Singgora tiles help to improve the comfort of building and reduce the demands for energy.

Figure 1.2 shows the installation of Singora tiles in the roof structure. According to Schunck (2003), type of roof installation is calls as double-lap tiling, which only one course of tiles is hung on each batten. He further mentions this installation forms ventilated roof covering because the air can flow in defined cavity beneath the installation. As a result, the ventilation system of the building is improved.

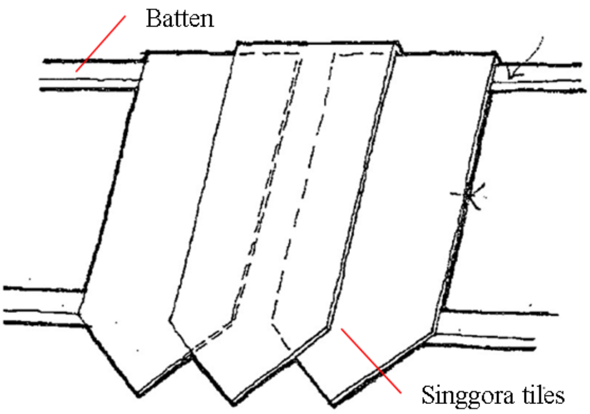

Figure 1.2: The installation of Singgora tiles
Source: USM (1991)

Adit (1994) had documenting the major growth and decline of Singgora tiles industry in Kelantan. He noted the Singgora tile industry was booming between 1950 and 1965 especially after the independence of the Malay States in 1957. The author states in 1960s, modern roofs were introduced into the Kelantan market when the road system between Kuala Lumpur and Kelantan was improved. He adds, towards 1965, the use and demand of Singgora tiles declined gradually and this continued up to 1970s, partly due to strong competition with other modern roofs available in the market.

Adit (1994) further states the emergence of the tobacco industry in 1963 which gave a relatively higher income, has affected the production of Singgora tiles industry due to shortage of labours. He adds, in 1970s, the demand for Singgora tiles decreased and many entrepreneurs began to shut down their operations. Shamsu and Zulkifli (2011) claim that since 1977 up to present, there was only one Singgora tile factory in Malaysia that was still operating and it became the sole supplier for conservation works and new traditional buildings.

Nowadays, most of the demand for Singgora tiles is for replacing the broken tiles in traditional buildings. The conservators of Malay timber house, Killman et al. (1994) note that Singgora tiles are fragile and this statement is supported by many scholars (Abdul and Wan, 2002; Loh, 2005; Zulkarnian and Norlizaiha, 2013 and Shamsu, 2013).

The changing in housing style also contributed to the decline for demand of Singgora tiles (Zulkarnian and Norlizaiha, 2013). The use of Singgora tiles in building is considered to be obsolete, old-fashioned and impractical with the present housing style. In many circumstances, the Singgora tiles are superseded by new product and users prefer to use the modern roofing. However, the use of Singgora tiles in traditional building is highly required in order to maintain the authenticity of building (National Heritage Department, 2012).

The decrease in demand becomes the main factor contributing to the decline of Singgora tiles industry. USM (1991) reports that Singgora tile was listed as endanger traditional building material. Unlike other ceramic craft industries, such as *Sayong* pottery in Perak, the industry of Singgora tiles is at risk as there is only one factory which has survived until today.

Preserving the local industry is vital in conserving and maintaining the authenticity of heritage building. For example, in North York Moors, England, the extinction of traditional limestone slates production has given problem to the conservation works (Scott, 2006). Therefore, in order to preserve the original building material of heritage building, the survival of Singgora tiles industry is crucial because they are the supplier for the conservation work.

Hidayah, Rodiah & Zuraini (2013) studied the community perceptions towards Singgora tiles by the age of the community members, and analyzing the potential for demand for Singgora tiles to develop in the market. This survey was conducted in June 2013 in Kota Bharu, the state capital of Kelantan. The results show that 78 % of the communities in Kota Bharu, Kelantan aged between 24 to 65 years old are interested to use Singgora tiles if the quality of the product is improved, relatively cheaper and available in market. In addition, 62 % of the communities aged between 9 and 23 years old also interested to use Singgora tile as roof covering for their houses in the future due to its aesthetic. They also report that the knowledge of respondent about the Singgora tiles is decreasing with age.

The aforementioned discussion shows the importance for improving the local industry of Singgora tiles. The material is a symbol for Malaysian architectural identity (Nasir & Teh, 2011). The demands from community show the potential for the industry to be developed. The sustainability of this local industry will create business to the local communities and contribute to the economic growth.

1.3 Justification of Research

Schunck (2003) notes the elementary function of roof is to provide protection from precipitation such as rain, snow and ice and to withstand the loads of wind, snow and persons carrying out maintenance and repairs. In addition, the nature of roofing material lends character to the building (Brunskill, 1992). Abdul and Wan (2002) note that the strength of property is the main criteria in selecting the building material. A faulty of roof will lead to penetration of rainwater through it and will become a source of problem to other structures (Feilden, 2003).

In Kelantan and Terengganu, the important of using Singgora tiles for repair and maintenance as well new construction has been emphasized by many scholars. For example, Lim (1987) notes the use of Singgora tiles are common for traditional Malay house in the East Coast of Malay Peninsula. Zulkarnian and Norlizaiha (2013) also described the use of Singgora tiles has preserved the architectural design of traditional building.

Killmann et al. (1994) note that Singgora tiles have low mechanical property and this creates the problem in conservation of traditional building where the dismantled and reinstalled of roof tile has to be carried out carefully. Figure 1.3 shows the example of broken tiles which happen in the middle of the roof. Briffett (1995) notes the tiles that lay on battens in old building allow the penetration of rainwater due to absence of insulation below them. The leakage due to cracked roof tiles, even small but continued over long period will be a risk to the building. The ingress of water results fungal decay to the timber and as a result, a structure may collapse (Feilden, 2003).

Figure 1.3: Broken Singgora tiles on the roof
Source: Field study (2013)

The use of low quality Singgora tiles also contributes to high maintenance cost in traditional Malay building as noted by Abdul and Wan (2002). They add, the common problem with Singgora tiles is associated with the breaking of hook. After break, the body of tile will slip downwards and leaves a gap thus allowing the ingress of water into the building. Figure 1.4 shows the tile that slip from its original position when the hook is breaks.

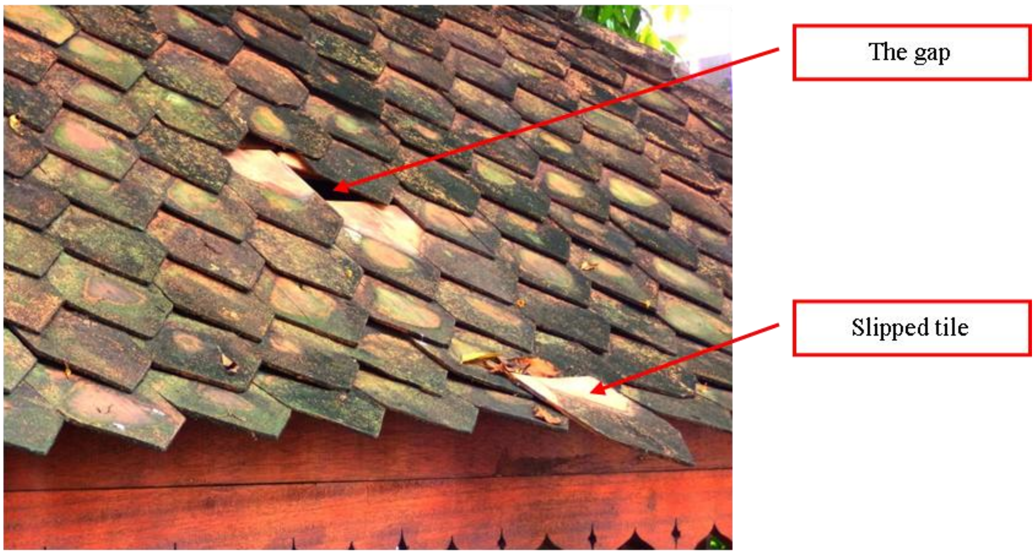

Figure 1.4: The broken Singgora tile slipped from its original position
Source: Field study (2013)

In addition, the fragile property of Singgora tiles caused the maintenance work to be carried out from the inside of the building. Unlike modern roofing material, people who carried out the maintenance work cannot walk on the top of the roof due to its brittle property (Loh, 1995). Figure 1.5 shows the view of Singgora tiles from the beneath installation. The replacement of broken tiles is carried out by inserting the tiles from below of the roof. Therefore, the installation of ceiling is inappropriate for building that used Singgora tiles roof.

Figure 1.5: The installation of Singgora tiles on the battens
Source: Field study (2013)

Forster and Kayan (2009) note two common problems dealing with maintenance of historic building are short lifespan material and scarcity of traditional material. The same factors were also identified by Killmann et al. (1994). They note the replacement of broken Singgora tiles is relatively expensive due to scarcity of material. The limited supplier has lead to the high price of material in the market. As a result, the cost per square foot of Singgora tiles is similar to modern tiles (Loh, 2005). Therefore, many users prefer to use modern roofing material instead of Singgora tiles.

The quality is the key determinant for the business success and growth (Chandra, 2001). Therefore, the quality of Singgora tiles need to be improved in order to survive, develop and sustain its industry. Warren (1999) notes the quality of clay product is strongly influenced by the technique of handling the clay, technique of forming the component and firing condition. Table 1.1 shows the focus of research by scholars in improving the quality of Singgora tiles.

Table 1.1: The previous researches

<table>
<tr><th>Focus of research</th><th>Justification</th><th>Scholars</th></tr>
<tr><td>Raw material</td><td>• Treated clay as raw material
• Mineralogical properties of clay
• Addition of flux or filler to clay</td><td rowspan="2">• Zulkarnian and Norlizaiha (2013)
• Shamsu (2013)</td></tr>
<tr><td>Manufacturing process</td><td>• Quality control procedure</td></tr>
<tr><td>Firing condition</td><td>• Firing temperature and duration</td><td>• Hidayah (2011)
• Naeem (2012)</td></tr>
</table>

In general, there are limited studies on Singgora tiles, particularly on improving the local product. Hidayah (2011) and Naeem (2012) have conducted a study related to the effect of varied firing time on the strength of Singgora tiles. They used the green tiles produced by local factory as a samples in their experiment and fired it at temperature 900ºC for 3 to 8 hours. However, their result of experiment is less accurate as the average value of strength is only based on three samples for each preference firing time.

Shamsu (2013) from University of Sciences Malaysia, although carried out the study to improve the Singgora tiles but his work focused on additive material to the clay and the design of tiles. The Singgora tiles used in his experiment was produced using treated Bris clay obtained from Bachok, Kelantan. He used the flux such as borax, grog, sodium chloride and talc to improve the quality of Singgora tiles. The samples were shaped to a few thicknesses and fired at the laboratory at temperature 800, 900 and 1000ºC for 12 hours. Other than raw material, an innovation on the original design of Singgora tiles was also adopted in his research.

Zulkarnian and Norlizaiha (2013), researchers from Universiti Teknologi MARA on the other hand, studied the effect of grogs in the Bris clay tiles and glazing. Like Shamsu (2013), the sample of tiles used in their researches was produced at laboratory using treated Bris clay. The samples were fired at temperature 900ºC and 1050ºC.

This study is focused on the green tiles product made by the local factory which similar to the study conducted by Hidayah (2011) and Naeem (2012). The study started with investigation on the process of making Singgora tiles at the factory. Next, the green tiles and fired tiles from the factory are collected and tested in the laboratory to determine their properties. Then, the green tiles are fired with electrical furnace at preference temperature and time and finally, its properties are tested.

1.4 Research Questions

The research questions for this study are:

1. What are the factors that affect the quality of Singgora tiles produced by local factory?
2. What are the physical and mechanical properties of Singgora tiles produced by local factory?
3. What are the effects of impurities and firing conditions on the physical and mechanical properties of Singgora tiles?
4. What is the optimum firing condition for making Singgora tiles?

1.5 Research Aim and Objectives

This research is aimed to improve the quality of the Singgora tiles. In particular, the objectives of the study are:

1. To identify the factors that affects the quality of Singgora tiles produced by local factory.
2. To measure the physical and mechanical properties of Singgora tiles produced by local factory.
3. To measure the physical and mechanical properties of Singgora tiles those are fired at various conditions.
4. To propose the optimum firing condition for making Singgora tiles based on optimum mechanical strength.

1.6 Scope of Research

The scope of this research is towards improving the quality of Singgora tiles produced by the local factory in Kelantan. In the study, no interference is introduced to the existing manufacturing method by the factory. The factory is operated using traditional approach with little help of machine. The research started by observing the manufacturing process of Singgora tiles at the local factory. It followed by randomly selected few green and fired products for testing its physical and mechanical properties. Lastly, a few green tiles from the factory are randomly selected and fired at several preference temperatures and times and then subject to be tested.

1.7 Research Methodology

Figure 1.6 shows the stages of research methodologies used in responding to research aim and objectives of this study. The methods used are case study and laboratory works.

The research starts with identifying the research problem through reading the conservation books, newspapers and previous research. Then, set of research questions are developed which need to be answered by the research. Next, the research objectives are constructed to which described the main steps in conducting this study.

The information gathered from literature review is used to develop the research design, aim and objectives as well as methods of data collection. Most of the literature is obtained from University of Malaya library database, thesis and dissertation, article in journals and newspaper, standards, books, government departments and official website.

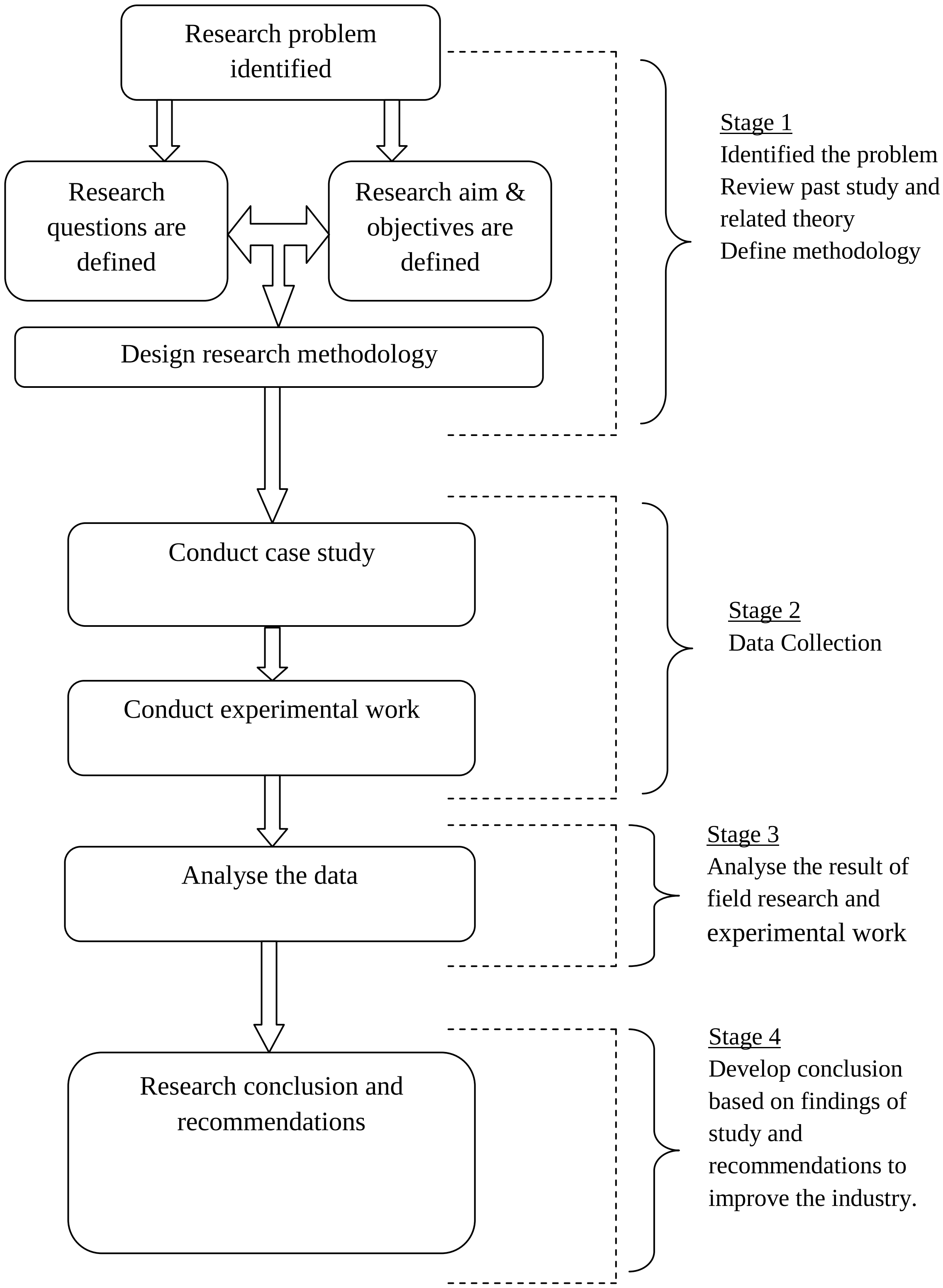

Figure 1.6: Research Process

The research methods used in this study are qualitative and quantitative. Table 1.2 shows the method of investigation in responding to research question.

Table 1.2: Research questions and method of investigation.

No	Research Question	Method of Investigation		
		Literature Review	Case Study	Experimental Work
1	What are the factors that affect the quality of Singgora tiles produced by local factory?	√	√	
2	What are the physical and mechanical properties of Singgora tiles produced by local factory?			√
3	What are the effects of impurities and firing conditions on the physical and mechanical properties of Singgora tiles?	√		√
4	What is the optimum firing condition for making Singgora tiles?			√

The case study is a local factory which produces Singgora tiles. The method used in the case study is observation. The investigation works are identifying the process of making Singgora tiles start from clay winning and preparation to the firing process. The inappropriate production methods and the defects that occur in the product due to these mistakes are identified through this observation.

Next, the experimental work is carried out to investigate the properties of Singgora tiles produced by the local factory (Experiment 1) and properties of tiles that fired at various temperatures and times (Experiment 2) as shown in Table 1.3. The entire test is performed at Building Laboratory, Faculty of Built Environment, University of Malaya except whatever stated.

Table 1.3: The test conducted on the Singgora tiles

Test	Standard	Experiment 1		Experiment 2	
		Green tiles	Fired tiles	Green tiles	Fired tiles
Surface quality	BS EN ISO 10545-2:1997	√	√	√	√
Dimensional accuracy	BS EN ISO 10545-2:1997		√	√	√
Percentage and type of impurities	-	√			
Water absorption	BS EN ISO 10545-3:1997		√		√
Flexural strength	ASTM C 1167-03		√		√

The Experiment 1 involves testing the properties of green tiles and fired tiles which randomly collected from the local factory. Whilst, the Experiment 2 is the experimental work for green tiles which randomly collected from the factory. It is worth mentioning that these green tiles are consisting impurities. The samples then fired at various firing conditions using electrical furnace and their properties is tested. The firing temperature used in this study is between 850 and 1050 ºC, which within the maximum temperature range in traditional kiln (Mason and Hill, 1999). In addition, the firing durations is varying between 4 to 14 hours.

Finally, the data obtained from the case study and experimental works is analysed. The results are presented in the forms of figure, graph and table. This information is used in the conclusion and recommendations of the research.

1.8 Research Contribution

The outcome of this study will benefit the local manufacturer, conservator, the Department of National Heritage and Malaysian Handicraft Development Corporation as well others interested party dealing with Singgora tiles.

1.9 Structure of the Dissertation

The structure of the dissertation is summarized as follows:

Chapter 1: Introduction

This chapter discusses the background of the topic, justification of research, research questions, aim and objectives, scope of study, research methodology, research contribution and structure of the dissertation.

Chapter 2: Literature Review

This chapter presents the background studies and related literature on Singgora tiles, clay, traditional production of clay product, ceramic and quality of clay roof tile. The discussion begins with a review on the research topic, Singgora tiles. The review then focused on the general properties of clay. Next, the discussion is concerns on the traditional method to make clay product. Later, the chapter discussed the properties of ceramic which made from clay. Finally, the chapter reviews the quality assessment for clay roof tiles.

Chapter 3: Research Methods

This chapter describes the methods adapted to achieve the research objectives. The research methods used are case study and experimental work. The case study is conducted to observe the manufacturing process of Singgora tiles at the local factory. In addition, the experimental work is carried out to examine the properties of the factory product and to investigate the influence of impurities and firing conditions on the properties of Singgora tiles fired in the laboratory.

Chapter 4: Results and Discussion

This chapter describes the results of case study and experimental works. The finding from case study consists of the manufacturing process and the factors contributed to the low quality of Singgora tiles. The results of experimental work discuss in this chapter are the properties of factory product and properties of the tiles fired at various temperatures and times in the laboratory.

Chapter 5: Conclusion and Recommendations

This chapter presents the conclusion from this research including the main findings, and research suggestion. The recommendations for further research are discussed at the end of the chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the background studies and related literatures on Singgora tiles, clay, traditional production of clay product, properties of ceramic and quality of clay roof tile. The discussion begins with a review on the research topic, Singgora tiles. The knowledge helps to connect this study to present research and adds the body of knowledge. The review then focused on general properties of clay. This knowledge is important in order to understand the characteristics of clay as a raw material to make Singgora tiles. Next, the chapter reviews the traditional production of clay product. Later, the discussion is concerns on the properties of the ceramic which composed of clay product. The knowledge on the ceramic properties helps to design the experimental works conducted in this study. Finally, this chapter reviews the quality of clay roof tiles. This information is important in helping to evaluate the result of experimental works.

2.2 Singgora Tiles

The traditional Malay building in Peninsula Malaysia can be categorized into palace, mosque and house. These buildings reflect not only the Malay community's customs and way of living, but also the skilled of craftsmen (Lim, 1987). Nasir and Teh (2011) note these buildings are generally divided into three main parts, consist of the pillars, walls and roof. Killmann et al. (1994) state that the roof is traditionally covered with organic and combustible material such as palm leaves and wood. They further state that these materials are relatively cheap but vulnerable to fire. There are many fire tragedy occurred in the past. For example, building's conflagration in year 1882 that occurred at *Istana Hijau* located in Terengganu had destroyed 1,600 houses in its surrounding area

(Tajuddin et al., 2004). Followed by this tragedy, the government has enforced a new regulation which building must be built with incombustible material such as bricks and terracotta tile roofs. The repeated fires subsequently forced the owners to shift to more expensive but safer terracotta tiles (Killmann et al., 1994). As a result, the use of Singgora tiles became popular In Kelantan and Terengganu (Adit, 1997).

The history of the manufacture of Singgora tiles in Malaysia is obscured due to lack of record. However, many scholars believed the industry was originated from the south of Thailand which was a part of the Malay Kingdom in the past (Adit, 1994; Salinger, 1997). Figure 2.1 shows the location of Kelantan and Thailand and the distribution of Malay ethnic over both countries.

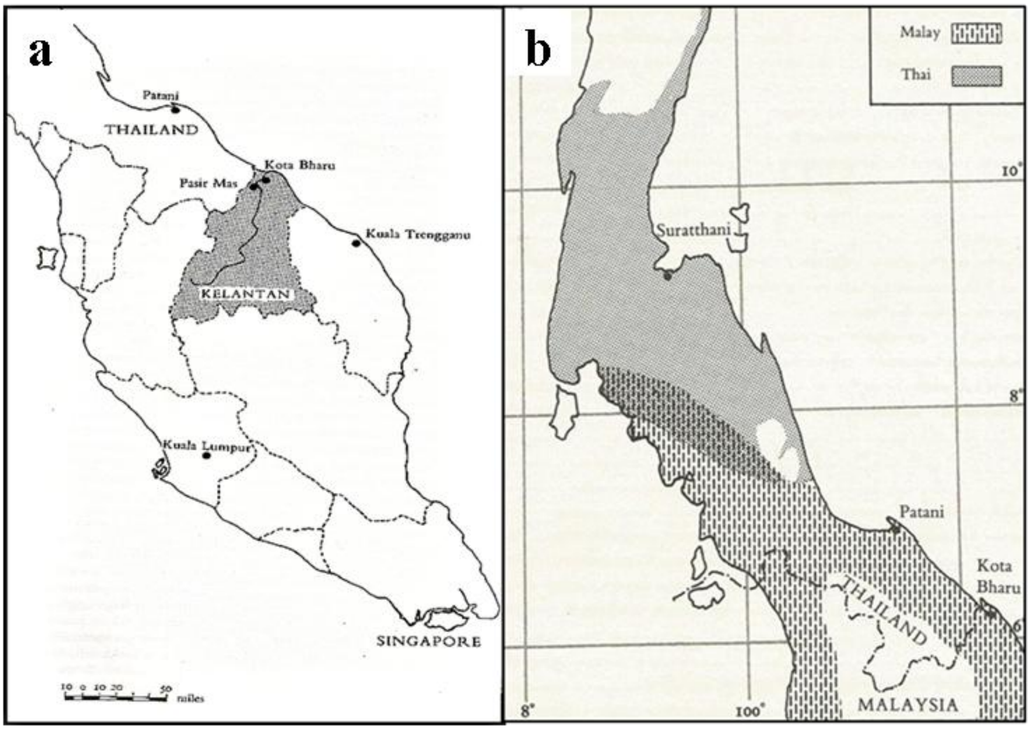

Figure 2.1: Location of Kelantan and Thailand (a) and distribution of Malay ethnic (b)
Source: Winzeler (1985)

In general, According to Shamsu and Zulkifi (2011), the name of Singgora tiles is referred to lion shaped mountain in Songkhla. The local name of Singgora tiles is "*Atap Bata*" (Adit, 1994). There are a few terms used by scholars that refer to Singgora tiles such as "*Genting*" (USM, 1991; Zulkifli, 1996; Salinger 1997) and Senggora tiles (Nasir & Teh, 2011).

Prior to the introduction of modern roofing material in Kelantan and Terengganu, most of the traditional buildings in Kelantan and Terengganu used Singgora tiles as roof covering (Adit, 1994). For examples, *Istana Jahar*, Balai Besar Palace, Tengku Sri Akar Palace, Kampung Laut Mosque, The State Council for Islamic Affair and Malay Custom's Building and Puchun Tat Watt (Nasir, 1979). Most of these buildings still maintain the use of Singgora tiles as roof covering. Figure 2.2 shows the use of Singgora tiles at Jahar Palace.

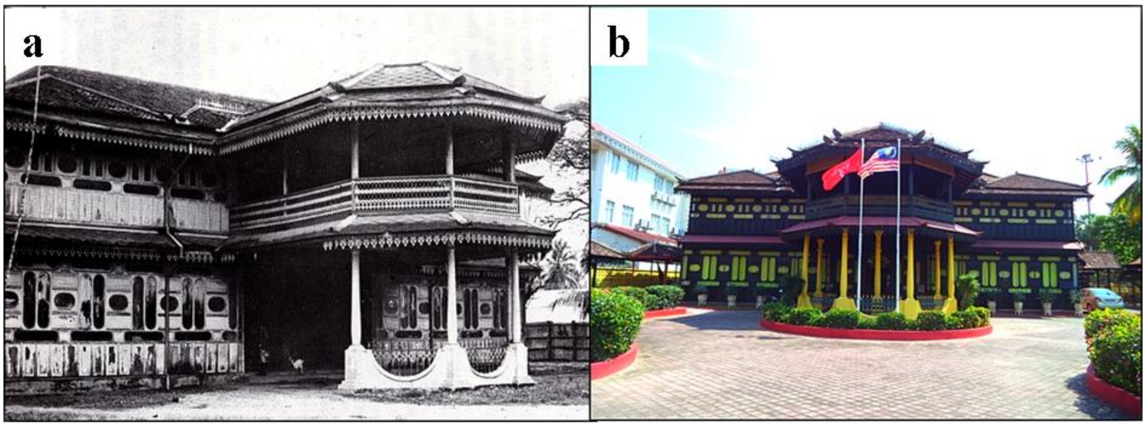

Figure 2.2: Jahar Palace built in 1887 (a) and after conservation work (b)
Source: Nasir (1979) (a) and field study (2013) (b)

Killmann et al., (1994) note that Singgora tiles has received the great foreign influence from Indo-China and Thailand due to historical and cultural traits. In Thailand, this roofing material is extensively used in both traditional and modern building; widely range from palaces to spirit houses (Sathāpitānon & Mertens, 2012). Figure 2.3 shows the example of Singgora tiles used in Thailand.

Figure 2.3: The building in Thailand that used Singgora tiles
Source: Sathāpitānon & Mertens (2012)

2.2.1 Small scale industry of Singgora tiles

Today, there is only one factory in Malaysia that still produces Singgora tiles which located in Bachok, Kelantan as noted by Shamsu and Zulkifli (2011). They further state this industry is operated by family and the product has limited market, but spread out over the country. According to Small and Medium Industries Development Corporation (2003), this industry is categorized as small scale enterprise. Based on United Nation Industrial Development Organization (UNIDO), under this category, the industry is carried on by artisans or traditional craftsmen who need assistance to modernize their skills, tools and technology of production (UNIDO, 1969).

Hashim (2005b) notes that there are many challenges and problems facing by the small scale industry in Malaysia. He further states that these problems are arising due to lack of formal education among the entrepreneur particularly in management and technical aspects. The similar finding is also reported by Rosman and Rosli (2011). Although they have an experience in the production line, but their knowledge is lack in terms of finance and marketing as stated by UNIDO (1969). They further mention that most of the entrepreneurs are unaware of the current market trend and unable to apply an appropriate adaption to their products. Shamsu and Zulkifli (2011) notes the Singgora tiles industry still using the out-dated tool and technology. Chee (1986) notes that this happen because small firms are lack in finance and they distrust the new technology. Hashim (2005a) notes the studies on small scale enterprise in Malaysia are limited. This includes the industry of Singgora tiles.

Rosman and Rosli (2011) notes the government plays an important role in supporting the development of small enterprises. According to Hashim (2005a), the small sector has been supported by the Malaysian Government due to their economic contribution. This includes the industry of Singgora tiles which received the financial support from Malaysian Handicraft Development Corporation (MHDC) (Faizul, 2011). Figure 2.4 shows the factory of Singgora tiles which received the allocation to upgrade its workshop.

Figure 2.4: The workshop before (a) and after (b) renovation
Source: Field study (2013)

Smith (1995) notes the quality of product is the main factor to attract the customer and to increase the sales. Hashim (2005a) states the decline in sale of over a long period by small industrialist is related to inability of manufacturers to improve the quality of their product. In addition, UNIDO (1969) describes that this happen because of lack of knowledge of entrepreneur on standards and techniques as well as tools for efficient production. In fact, the decline of Singgora tiles industry is associated with the inferior quality of the product (Killmann et al., 1994; Abdul & Wan, 2002; Shamsu & Zulkifli, 2012 and Zulkarnian & Norlizaiha, 2013). Figure 2.5 shows the summary of challenges and problem facing by entrepreneurs and its reason.

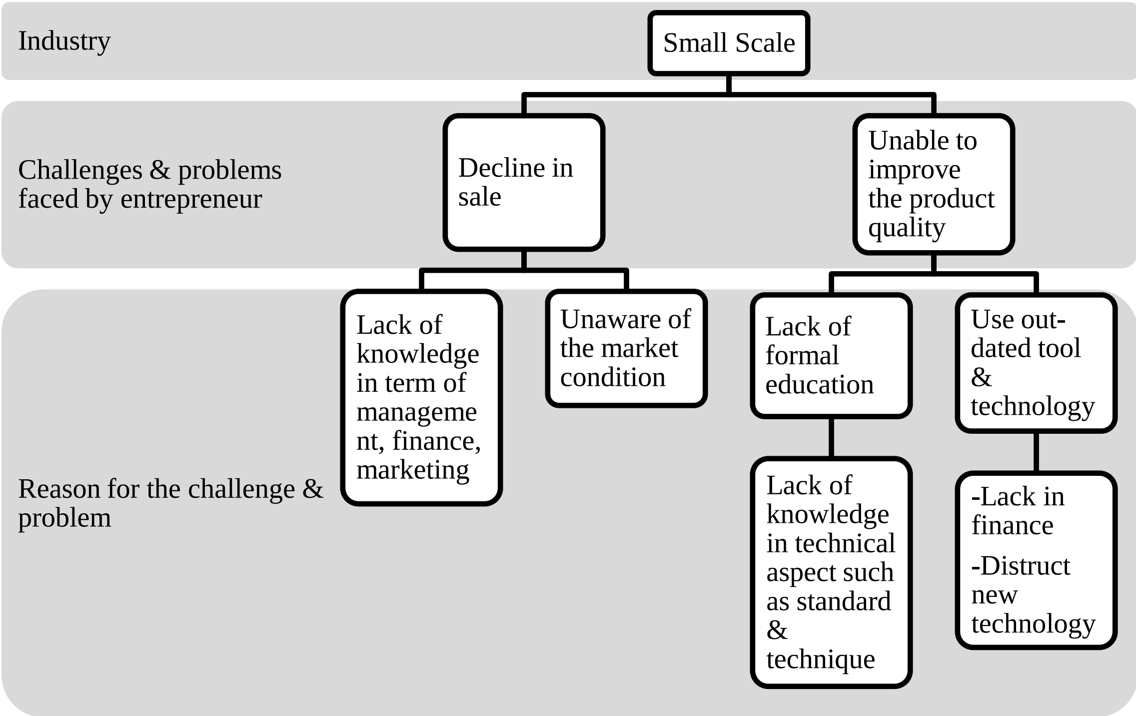

Figure 2.5: Challenges and problem facing by entrepreneurs and its reason.

2.2.2 A review of previous research

The information on Singgora tiles is much less than others clay product. Most of the researches related to Singgora tiles are focus on its traditional making process (USM, 1991; Adit, 1994; Zulkifli, 1996; and Shamsu and Zulkifli, 2011). However, there is lack of study conducted in improving the quality of Singgora tiles (Hidayah, 2011; Naeem, 2012; Shamsu, 2013; Zulkarnian & Norlizaiha, 2013).

Making the Singgora tiles

USM (1991), Adit (1994), Zulkifli (1996) and Shamsu and Zulkifli (2011) documented the process of making Singora tile. The similarity in making process as documented by them shows that the industry of Singgora tiles has preserved their traditional technology and skill. They described the process of making Singgora tiles is divided into four stages. First, the clay winning and preparation followed by forming the shape of tiles. Next, the green tiles are dried under the sun. Finally, the tiles are fired with traditional kiln.

The review on the literature shows that the Singgora tiles are produced using untreated clay. Therefore, the bad quality of clays is used. The clay is only wedged by barefoot after the addition of water. After that the clay is put into the mould which pre-coated with rice husk ash for easy released. Then, the surplus clay is trimmed with bow-wire to reach the desired thickness. Next, the shaped clay is carefully de-moulded onto a pallet. The wet green tile is dried under the hot sun and during drying; the straight end of the green tile is bent upright to form the hook. After dried, it is loaded into the kiln and the firing process starts using light fire followed by large fire. Then, the tiles are left to cool naturally inside the kiln for one month.

Although the production of Singgora tiles is well documented by aforementioned researchers, they did not relate the formation of defect with the making process.

Properties of raw material to produce Singgora tiles

The raw material for making Singgora tiles is Bris clay (Shamsu and Zulkifli, 2011). Studies conducted by Shamsu (2013) and Zulkarnian and Norlizaiha (2013) show that the main composition of clay is silica (SiO_2) followed by alumina (Al_2O_3) in the range of 62 to 64% and 23 to 25% respectively.

Quality improvement of Singgora tiles

There are a few researchers focus on improving the quality of Singgora tiles. Study has been conducted by Hidayah (2011) and Naeem (2012) related to the effect of varied firing time on the strength of Singgora tiles. The samples used in their experiment were green tiles collected from the local factory located at Bachok, Kelantan. These green tiles which consist of impurities were fired at temperature 900°C for a few different hours. Figure 2.6 shows the combination of flexural test result obtained by them. The result of strength for samples fired for 3 hours is obtained by Hidayah (2011) while the others result is obtained in the experiment carried out by Naeem (2012).

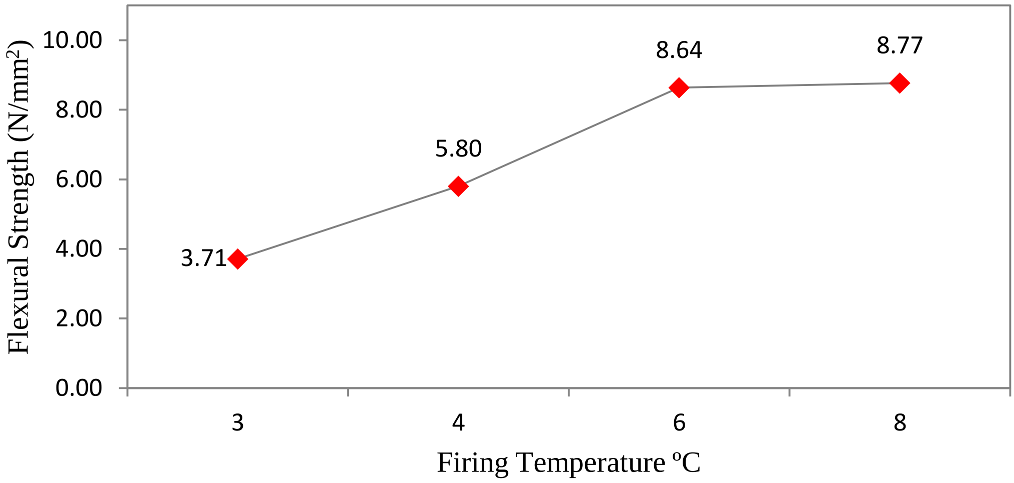

Figure 2.6: Graph flexural strength against maximum firing time by Hidayah (2011) and Naeem (2012)

According to Figure 2.6, the strength of Singgora tiles is significantly increased as the duration for firing is increase from 3 to 6 hours. However, a small change of strength was observed on further heating to 8 hours. This graph indicates that the high flexural strength of Singgora tiles can be achieved when fired for 6 hours and above. However, it is worth mentioning that the data of strength in Figure 2.6 is less accurate as the value is based on the average strength for 3 samples for each preference firing time.

Apart from that, a few researchers also conducted a study to improve the strength of Singgora tiles but not on the existing product. In their experiment, they prepared the samples of Singgora tiles in the laboratory by treating the clay to remove the impurities.

One of them is Shamsu (2013) from University of Sciences Malaysia. He studied the effect of flux addition in the clay, thickness of sample and firing temperature on the water absorption and strength of Singgora tiles. The samples are fired at temperature 800°C, 900°C and 1000°C for 12 hours. The result shows that there is no effect of firing temperature on the water absorption of Singgora tiles produced using treated clay. The consistent value of water absorption is 18.5 %. However, the strength of tile is increased with the increased of firing temperature as shown in Figure 2.6. The best strength of Singgora tiles was given by the 7mm thickness samples and tiles which added with lithium in its raw material. Both of these samples were fire at temperature 1000°C.

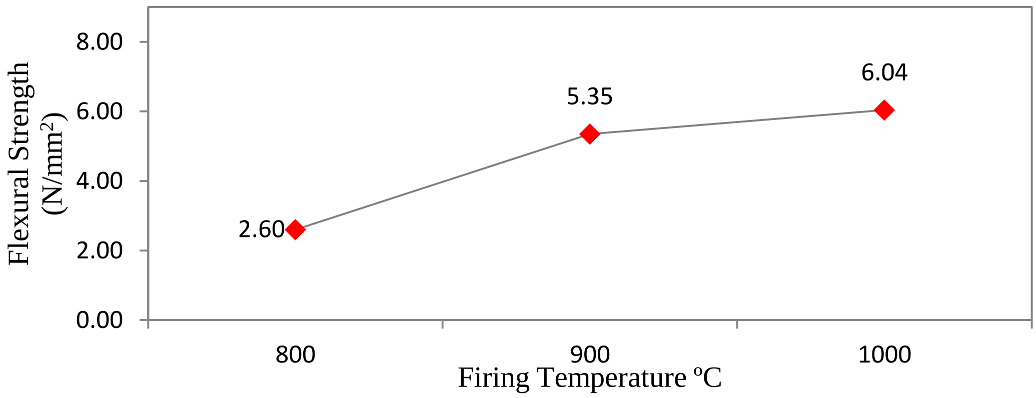

Figure 2.7: Graph flexural strength against maximum firing time by Shamsu (2013)

In addition, Zulkarnian and Norlizaiha (2013) had conducted a study to improve the quality of the raw material and physical appearance of product. In their experiment, they add 2% of grog into the treated clay and fired the sample at temperature 900 and 1050 for 8 to 12 hours. The addition of grog has increased 12.5% strength of product. The maximum compressive strength achieved by the tested samples is 7.2 MPa.

Besides, the glaze was applied to the surface of Singgora tiles which make it resisted to water and created the colour on the surface. Other than grog and glaze, oxide was also added to the clay to give variety of colours to the body of tile. Figure 2.8 shows the innovation on product produced by them.

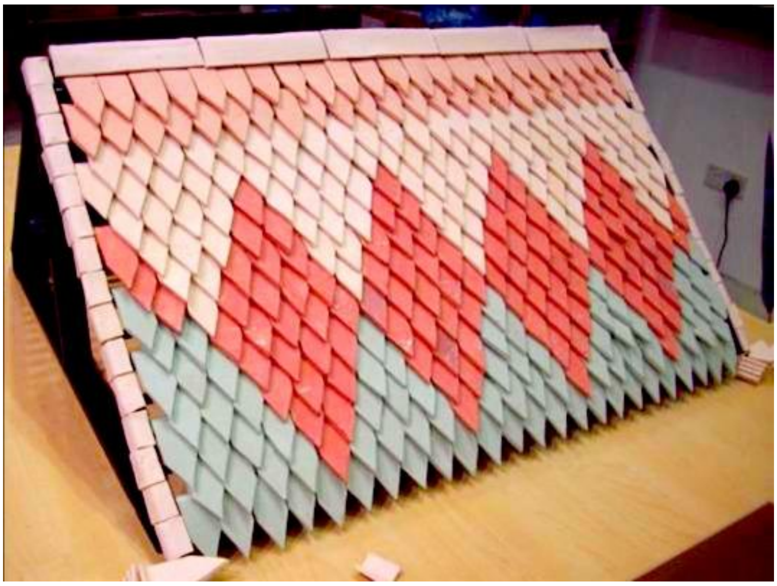

Figure 2.8: Innovation in the raw material and design of Singgora tiles
Source: Zulkarnian and Norlizaiha (2013)

Table 2.1 shows the summary of finding related to the quality of Singgora tiles in term of physical and mechanical properties.

Table 2.1: The finding from previous research

Green sample taken from the local factory	
Experiment	Finding
Firing time	The strength is increased with the increased of firing time especially at 6 hours
Sample prepared in the lab using treated clay	
Experiment	Finding
Addition of flux	The addition of Lithium has given the best strength when fired at 1000ºC. The addition of oxide has give variety of colours to Singgora tiles.
Addition of filler	The addition of grog has increased the strength of Singgora tiles.
Thickness of tile	7mm thickness of Singgora tiles which fired at 1000ºC has given the best strength.
Firing temperature	No effect on water absorption (consistent value). The strength is increased with the increased of firing temperature.

2.3 Clay

Clay is raw material used to make Singgora tiles (USM, 1991). Clay is defined as a rock resulting from either the disintegration of pre-existent crystalline rocks or a formation inside large sedimentary basin (Boch & Nièpce, 2006). It is describes as impermanence material because of its nature; viscous when wet, brittle when dry, and transform into stone-like permanence material when subject to fire (Leon, 2008). The different type of clay has varies considerably physical properties, hardness, colour and mineralogical content.

2.3.1 Properties of clay

Table 2.2 shows the characteristic of clay at different physical states.

Table 2.2: The characteristic of clay at each physical state

Physical states	Characteristic
As dug	• Lumpy non-homogeneous clay • Contain a variety of foreign bodies such as vegetable matter and stones • Unsuitable for use if foreign material is not removed
Slurry	• Clay softened in water • Before sieve, it is lumpy and uneven • After sieve, it is known as slip
Plastic	• Have approximately 25% water content • Suitable for throwing and modelling • Not sticky or crack if rolled into a coil • Warped round a finger
Leather-hard	• Slightly bend • Ideal for turning on the wheel, carving or incising, and slab building • Support its own weight
Dry	• Very fragile and brittle states • Tends to show lighter at the edges • If scratched the clay comes away as powder
Biscuit	• Changed its physical state once exposed to fire • The body is strong, non-soluble and porous

Sources: Cooper (1970)

The clay in dug state is unsuitable for making ceramic because it consist of impurities. For making Singgora tiles, the suitable physical state of clay is plastic state because it can retain the shape after de-moulded.

Figure 2.9 shows the main elements commonly found in clay. Brown and Gallagher (2003) state these elements are clay minerals, accessory minerals and impurities. They note the amount of these elements has great influences on the composition and properties of clay as well its products.

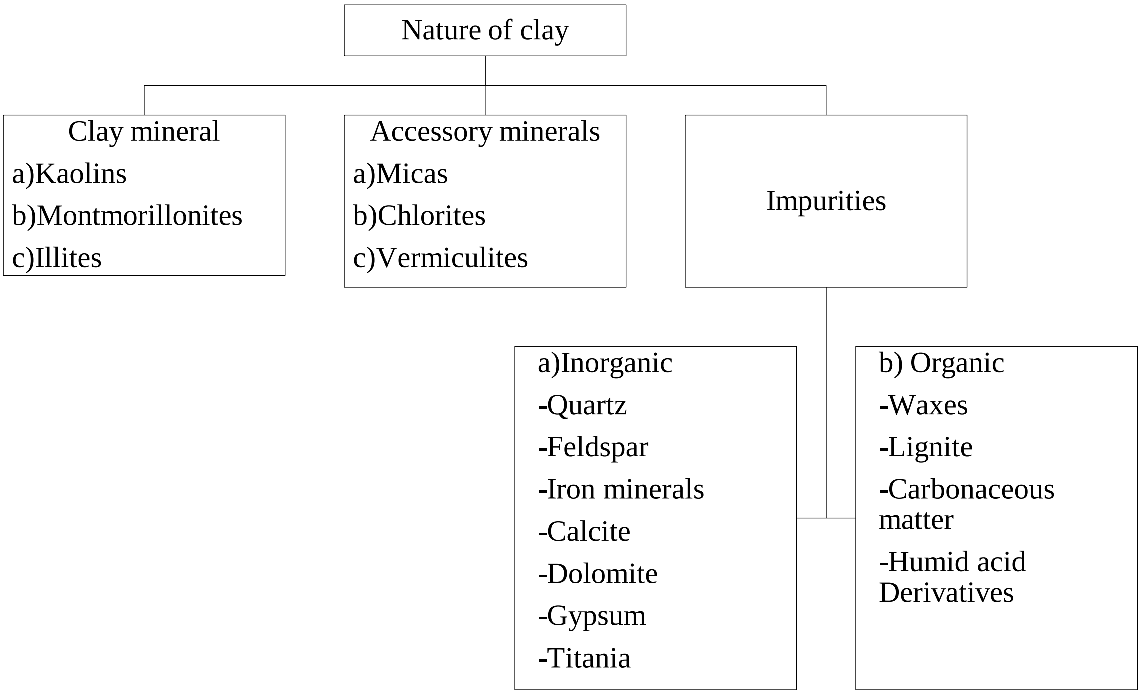

Figure 2.9: Clay minerals, accessory minerals and impurities in clay deposit
Source: Brown and Gallagher (2003)

Clay minerals are use to give plasticity which bind others material together and vitrify when subject to firing (Reeves, Sims & Cripps, 2006). For examples, illite produces the plasticity and kaolinite acts as glue owing to its good sintering property (Bektas et al., 2007). The presence of high amount of organic matter in the clay will make it more plastic with greater dry strength (Norton, 1974; Worral, 1982). To study the properties of clay mineral, the organic matter should be removed by digestion in a hydrogen peroxide solution and this method will not destroy the crystal structure

(Norton, 1974). Bektas et al. (2007) notes that the quartz act as stabilizer in the mixture and limits the drying shrinkage as well improves the void structure. Quartz also provides the product strength and stability as stated by Reeves et al. (2006).

Table 2.3 shows the ideal distribution of grain size of the soil. Worral (1982) notes that the low strength of green tiles is strongly related to less fine grain size and less organic matter. He further states that the high dry strength is depend on the proportion of clay substance, its fineness, exchangeable cations and the amount of organic matter that present.

Table 2.3: Ideal grain size of raw material for making bricks

No.	Element	Size	Recommended value
1	Sand	2mm to 0.063mm	20-45%
2	Silt	0.063mm-0.002mm	25-45%
3	Clay	<0.002mm	20-35%

Source: Mueller et al. (2008)

Buys and Oakley (1993) note the clay can be designed for a specific purpose. They further state that this clay is known as ‘bodies’ which formed by adding the filler and fluxes. The filler is non-plastic materials which functioning to retain the shape of clay during firing. Whilst, flux is substances that naturally exist or purposely added which functions to lowers the fusion point of material (Dodd & Murfin, 1994).

The mineral composition in clay imparts the colour of the fired clay (Norton, 1974). Other than iron content, the present of oxygen or also known as oxidation has produces a wide range of colour of product (Lynch, 1994). The high percentage of ferric oxide in the clay has yield red or brown product, and the colour also indicates the temperature in the kiln (Searle, 2012). Table 2.4 summarize the elements in the clay in its contribution to the product.

Table 2.4: The elements of clay and its contribution to the product

Element	Description
Illite	Produce plasticity
Kaolinite	Act as glue due to its good sintering property
Organic matter	Develop dry strength
Quartz	Act as stabilizer to give stability to the product Limit the drying shrinkage Improve the void structure Provide product strength
Iron	Give colour to the product
Filler	Retain the shape of clay during firing
Flux	Lower the fusion points of clay bodies

2.3.2 Bris clay as raw material to make Singgora tiles

Bris soil is the clay that predominantly found in East Coast of Malaysia (Shamshuddin, 1990). Roslan et al. (2010) notes the name of Bris is an abbreviation for ‘Beach Ridges interspersed with Swales’. This name describes the nature of soil properties and its distribution in the coastal landscape. However, Shamshuddin (1990) notes the name is derived from the place, called as Beris which located in Kelantan. He further states Bris soil is very sandy with low fertility.

Table 2.5 shows the fraction and percentage of Bris soil. The main mineral in the Bris soil is quartz, which hard to weather (Roslan, Shamshuddin, Fauziah & Anuar, 2010). Toriman, Bakar, Gazim and Azia (2009) note the average temperature of bris soil at noon is 31.2 ºC. They further state that this high temperature has accelerated the nitrogen vaporation and moisture. As a result, the moisture content of Bris soil is low because it cannot retain the water for long duration.

Table 2.5: Component of the Bris soil and its percentage

Fraction of Bris soils	Percentage (%)
Sand	95-99
Silt	0-23
Clay	0-3.2

Source: Roslan et al. (2010)

2.4 Traditional Production of Clay Product

The traditional production is adopted in making the Singgora tiles. This chapter presents the traditional methods used to make the clay product such as bricks, tiles and potteries. Figure 2.10 shows the common production stages for clay product as noted by Lynch (1994).

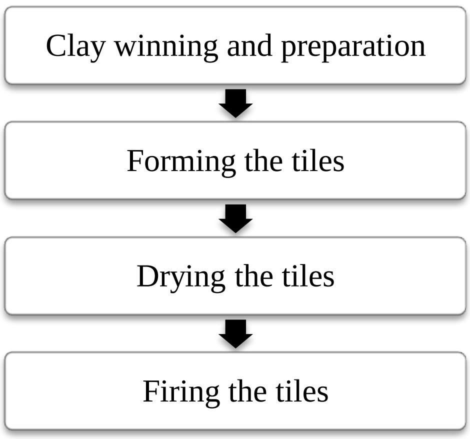

Figure 2.10: Sequence of production stage for clay product

2.4.1 Clay winning and preparation

According to Warren (1999), soil is a suitable soil for making brick and other fired building materials. He further mentions that the clay is obtained from formerly compacted clay-rich deposits, solidified in the earth crust as mudstones or shales. He notes the selection of clay is crucial because of the variations in deposited-earth. West and UNIDO (1969) note that any varieties in raw material are to be avoided and the unwanted constituent or impurities are best left in the pit neither by selective winning nor by selection from the won material. Dodd and Murfin (1994) defined winning as the combined process of getting or excavating, and transporting a raw material such as clay to a brickworks or stockpile. Pollio (1960) notes the selection of raw material is essential to improve the performance and durability of the bricks.

Most of the clay requires certain preparatory process before being used to make the product. Warren (1999) notes that traditional method of mixing is done manually by forking over, treading by animals and trading by human feet, which allows the large unwanted particles such as pebbles to be detected and removed. Lynch (1994) states the preparation processes are involve crushing, grinding and mixing the clay to reduce its particle size. The common faults at this stage are related to the quality of clay, uneven mixing and failure to separate out the foreign material as mentioned by Warren (1999). He further mentions that the clay can be wetted into slurry and then sieved to screen out the largest components whose presence caused the developments of cracks to the finish product.

The raw material is improved by adjusting the balance of sand, clay and silts as well the appropriate amount of water to provide sufficient plasticity to be worked (Warren, 1999). Cooper (1970) notes the clay bodies will become tougher or rougher by the addition of various ingredients such as grog and sand. He further states that grog is fired clay which ground down to various sizes and give body strength and texture. The grogs used to limit the drying shrinkage by reducing the amount of water between the layer and particle of clay (Van Vlack, 1964). On the other hand, up to 10 per cent of sand can be added to the clay to make a body stronger and more open throwing (Cooper, 1970).

2.4.2 Forming the green product

The aim of shaping the component before firing is to model the amorphous material into a rigid object which dries to the touch before fired as stated by Warren (1999). He further notes the clay is remain plastic when formed, thus it must be moved with care until further drying brings it to handleability. The traditional method to shape roofing tiles is usually produced by hand from clay lump or clots (West & UNIDO, 1969). Lynch (1994) notes the lump of clay is thrown by hand into a frame mould and rolled in moulding, which yield individual and attractive bricks.

2.4.3 Drying the green product

The drying process is an important stage for the green tiles to allow them to shrink, thus prevent twisting and cracking in the kiln as noted by Lynch (1994). He also states that the drying is held either naturally outdoor or drying chambers where bricks are left on pallet so that a flow of heated air can pass over them. According to Dan, Přikryl and Török (2009), the green tiles are dried in a covered space, a shelter construct with scraps of wood and roofed with straw thatched, which this shelter also known as hovels. They further note that this method is inexpensive but required a lot of free space and severely affected by climate conditions.

The poor handling during the drying stage could produce misshapen product as noted by Warren (1999). He further mentions the traditional method to move the relatively fragile green bricks is using sprung barrows or cart and dried under the shelter of light timber covers or hacks or in open sided buildings. The main difficulty dealing with tiles making is preventing the tile warping out of shape as mentioned by Cooper (1970). He further states the warping of tiles is prevents by the addition of 25 per cent of grog, slow and even drying and the size of tiles must not be too large or too thin and the ideal area and size of thickness is 15.24 cm^2 and 1.27 cm respectively.

2.4.4 Firing the green product

The final stage in traditional production of clay product is the firing process. The traditional kiln is used to fire the product. Dodd and Murfin (1994) defined a kiln as a high-temperature installation used for firing ceramic ware or for calcining or sintering. Adjorlo and Kaza (2007) describe the kiln as thermal insulated chamber or oven which its temperature can be controlled to fire the ceramic product either in individual or industrial levels. The setting of kiln consists of three components consist of an opening to load the pottery and the fuel, inner chamber to put the green product and exit for the heated air to create both proper ventilation and air circulation (Adjorlo & Kaza, 2007). UNIDO (1984) classified the types of kiln according to their method of operation, either intermittent or continuous as shown in Figure 2.11.

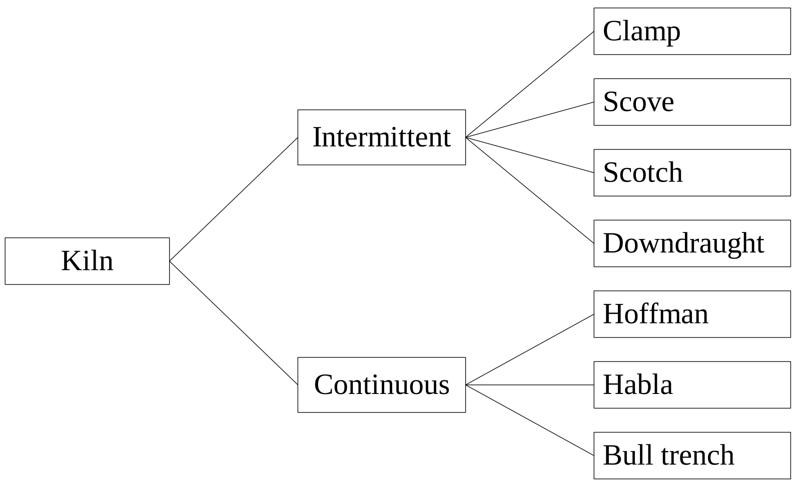

Figure 2.11: Type of kiln and their method of operation.
Source: UNIDO (1984)

According to Mason and Hill (1999), the range of maximum temperature achieved by the traditional kiln is 900 ºC to 1000 ºC. The downdraft kiln should be used if the even temperature of firing is required, but updraft kiln is preferable if space become the priority (Adjorlo & Kaza, 2007). Jenkins and Mullinger (2008) note the operation of primitive furnaces is very inefficient because the energy required for the chemical changes is quite small compare to the energy consumed in heating up the pottery. They further describe that the furnace structure is large and the heat is lost when the furnace and product are allowed to cool prior to being recovered for uses.

Intermittent Kiln

Laefar, Debra, Boggs & Cooper (2004) note the construction of intermittent updraft kilns comprised of the enclosure of bricks, opening to insert the fuel which located at the base and a chimney. The shaped of intermittent kiln can be circular, rectangular or oval shaped and constructed either updraught or downdraught (Punmia, Jain & Jain, 2003). There are several types of intermittent up-draught kiln such as Scove, Scotch and clamp kiln.

This kiln is operated by deflecting the heat from the burning fuel to the permanent roof kiln, then flows down between the gaps of green bricks to warm and burn them (UNIDO, 1984). Punmia et al. (2003) note the operation of intermittent kiln is discontinued, which the process start by loading the green bricks into the kiln, the fire is ignited to burn the bricks, the fired bricks then allowed to cool off and finally unloaded. The downdraught kiln produces greater quality of product due to greater distribution of heat (Ritchie, 1980; Punmia et al., 2003). In comparison, the loss of heat in the updraught kilns is in the range 25 to 40 % while the downdraught kilns only 10 % (Ritchie, 1980). The use of intermittence kiln is adaptable in changing market demand but it is inefficient in terms of the use of fuel (UNIDO, 1984).

Scove kiln

UNIDO (1984) describes that the Scove kiln is constructed by laying the burnt bricks as a base and the tunnel which acts as fire box is built on top of that base. Before the firing starts, the external wall of kiln is plastered with mud and the top of the laid green brick in the chamber is covered with closely packed of fired bricks. Afer firing, the wall of this periodic kiln is demolished to unload the bricks (Ritchie, 1980). Kreh (2003) notes the operation of Scove kiln is inefficient because it is produce a varied quality of product, which depends on its location in the kiln.

Scotch Kiln

Bricks that have little imperfections or 'second' grade from the clamps can be used to build a Scotch kiln (Heeney, 2003). The Scotch kiln are categorized as intermittent type that need to be filled, heated, cooled and emptied in each firing episode (Cressey, Strachan & Suddaby, 2010). UNIDO (1984) notes that Scotch kiln has similar design to Scove kiln, but the bricks that used to construct it are permanently mortared. They have no permanent top but the doorway is constructed at the wall. During firing, the doorway is temporarily closed with fired brick. The output of Scotch kiln is inefficient due to poor control of firing cycle (Heeney, 2003).

Clamp Kiln

There are two types of clamp kiln, which open and closed design as mentioned by Heeney (2003). UNIDO (1984) notes there are three or four holes are constructed at the edge of clamp base which act as a channel to ignite the fuel bed. Two layers of fired brick are laid on top of green brick. Sometimes, a thin bed of fuel is laid on top of that brick.

Continuous Kiln

The operation method of chamber in the continuous kiln is describes as; when the first set of chamber were being fired, the bricks in the next chamber are getting dried and preheated while the bricks in the third chamber are loaded and the last chamber is being cooled (Chandigarh, 2001). These kilns produce a constant rate of output because the fired bricks are continuously removed and replaced by green brick in other chamber and then heated as stated by UNIDO (1984). They further mention that the heat released by brick during cooling stage is used to heat up the green bricks in another part of the kiln. This use of fuel to operate this kiln is saves compared to other types of kiln (Chandigarh, 2001).

2.5 Ceramic

Dodd and Murfin (1994, p. 56) define the ceramic as “non metallic inorganic or carbon solids, artificially produced or shaped by a high temperature process, and inorganic composites wholly or essentially comprising such materials”. Ceramic tile is defines as the slab made either from clays or other inorganic raw materials (BSEN14411:2006). Schunck (2003) categorised clay roof tile as a ceramic building materials. This section will discuss the properties of ceramic made from clay. These materials are brick, pottery and roof tile, including Singgora tiles.

2.5.1 Firing the ceramic product

Rhodes (1968) notes the firing properties are an important element to produce great quality of ceramic. He further mentions that the action of fire will give the hardness and permanent shape to clay and yield a range of colours to the ceramic product. Dodd and Murfin (1994) describe the firing as a process of heat treatment for ceramic ware in a kiln which develops a vitreous or crystalline bond, thus giving the ware properties. They further state that burning is an alternative term for firing but less appropriate. In addition, Cooper (1970) defined a firing of ceramic as a process to produce insoluble product by subjecting the clay to the heat either in a kiln or an open fire. On the other hand, Remmey (1994) notes the firing is a process where compacted ceramic powders or clay are heated at high temperature to develop its chemical and physical properties.

According to Karaman, Ersahin & Gunal (2006), the temperature required for firing is depended to the clay material and density, and the desired degree of hardness and colour. During firing, a series of transformation occur in the clay minerals and accompanying minerals which determine the final properties of ceramic (Jordan et al., 2001). According to Remmey (1994), the firing will reduce the porosity and increase the density of product. The firing or also known as sintering will reduce both the surface area and bulk density and increase the body strength of ceramic (Van Vlack, 1964).

Table 2.6 shows the reaction in ceramic bodies when subjected to heat. Right coordination of firing procedure is the key determinant to produce a product with even colouring, zero cracks and dimensional accuracy (Schunck, 2003). A successful firing of clay body is achieved when their strength and degree of vitrification is develop without deforming (Fraser, 2000).

Table 2.6: The reaction of ceramic bodies when fired.

Temperature (ºC)	Reaction in ceramic bodies
200	• Use slow rate of firing speed to boil away any traces of pore water. • Fast rate of firing cause the product to crack and explode due to steam pressure
450-500	• Dehydration period: chemically-bound water begins to dissociate from the clay mineral. • The carbonaceous materials are burned away.
Above 600	• Chemically-bound water has been driven off. • Deposits at the surface burn away. • Combustion of organic material below the surface layer is less quick.
900 and beyond	• Burning of organic matter * If the firing speeds too quickly especially at temperature between 600-1000 °C, organic matter remaining in the ware may be sealed in by the vitrifying surface layer of the ware.

Source: Fraser (2000)

Table 2.7 shows primary bonding system, either vitrification or sintering, of the ceramic product. Vitrification is a progressive reduction and elimination of porosity in a ceramic composition with the formation of glass phase resulting from heat treatment as notes by Remmey (1994). He further states that the formation of glass phase typically starts around 1100 ºC and it will accelerates with the further increment of temperature. Bernasconi, Diella, Pagani, Pavese, Francescon & Tunnicliffe (2011) notes that firing duration is the key parameter to promote the vitrification, where increasing in firing time will decrease the water absorption. Lynch (1994) notes the vitrification is the production of a glass-like bond cementing the particles together which giving strength to the brick. The vitrification of ceramic occurs at temperature 1000 ºC (Van Vlack, 1964). However, Schunck (2003) notes the closed pore of clay roof tiles is occurs at temperatures between 1200 ºC and 1300 ºC.

Table 2.7: The type of ceramic product and their bonding system

Type of ceramic product	Primary bonding system
Structural clay (Bricks, roofing tiles) Abrasives Fireclay refractories Whiteware	Vitrification
Basic refractory Ferrites High alumina Pure oxides Pure carbides	Sintering

Source: Remmey (1994)

2.5.2 Factors affecting the properties of ceramic

Schunck (2003) notes the temperature and duration of firing affect the weathering resistance and hardness of the tiles. A number of studies have been conducted regarding these factors. Figure 2.12 shows the relation between firing temperature and the ceramic strength as noted by Rice (1998). According to this figure, the strength of ceramic is increased with the increase of firing temperature and duration. Besides, the porosity is decreased when the temperature and time are risen. Moreover, the increased of grain size has reduced the strength as the firing temperature and time increased.

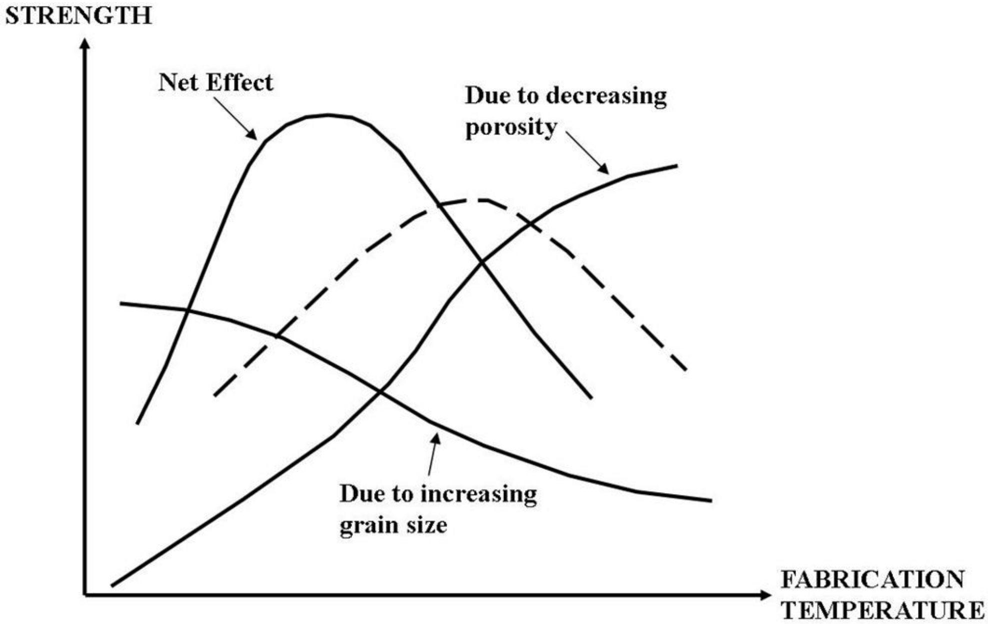

Figure 2.12: Graph strength against fabrication temperature
Source: Rice (1998)

A similar result is also reported by Manoharan, Sutharsan, Dhanapandian, Venkatachalapathy & Asanulla (2011). They note the increase of firing temperature between 900 ºC to 1000 ºC lead to the increase of compressive strength and decrease of water absorption. They explain the decrease of water absorption for the ceramic fired at temperature above 1000 ºC is associated with the formation of considerable liquid phase. The liquid phase penetrates into the pores and creates isolated pores. A similar observation is also described by Bernasconi et al. (2011) and Sidjanin et al. (2007).

Sidjanin et al. (2007) explains the mechanical properties of clay tiles are depending on the mineral composition in raw material. Cultrone, Sebastia'n, Elert, Torre, Cazalla & Rodriguez-Navarro (2004) notes the absence of carbonates in clay results in a reduction of porosity and significance increase of pore fraction as the firing temperature increased.

Study by Monteiro and Viera (2004) show that the water absorption is decreased with the increasing of firing temperature. They further mentioned that both linear shrinkage and flexural strength are also increased with the increasing of firing temperature. They note the flexural strength is sharply increased at the firing temperature above 1000 ºC. The presence of organic matter in clay leads to low mechanical strength and formation of microstructure cracks and dark spots.

Ece and Nakagawa (2002) explain the relationship among firing temperature, bending strength and bulk density of porcelain. They results show the bending strength and bulk density are increased with the increasing of firing temperature. They add the porcelain loses its strength when fired above the sintering temperature due to bloating of isolated pores and disappearance of quartz as well the decrease of bulk density.

Stathis Ekonomakou, Stournaras & Ftikos (2004) state the properties of porcelain are affected by firing time, soaking time, filler grain size and quartz content. They note the main factor that contributes to the physical and mechanical properties of porcelain is the filler grain size. They add, the use of coarse grain quartz has reduced the bending strength due to the formation of detrimental microstructure.

2.5.3 Ceramic properties assessment

The section describes the physical and mechanical properties of ceramic.

2.5.3.1 Physical properties

Dan et al. (2009) note the properties of chemical, mechanical and durability is strongly influenced by the porosity of clay product. The porosity is defined as:

$$\text{Porosity} = \frac{\text{Volume void space (including pores \& } cracks\text{)}}{\text{Total volume of the specimen}}$$

Cuff (1996) notes the appropriate methods to determine the porosity of ceramic is through water absorption test. He further states that the reduction in porosity will decrease the water absorption. The maximum bending strength is attained when the porosity near to zero (Ece & Nakagawa, 2002). Dan et al. (2009) note the water absorption in brick contributes to the deterioration and reduction of mechanical strength. They further state that the water absorption is determined by the capacity of fluid to be stored and circulated in the pores. Whilst, the pores dimension and its distribution are affected by the quality of clay, amount of water and the presence of additives or impurities as well the firing temperature.

Felhi, Tlili, Gaied & Montacer (2008) note the porosity can be reduced by using the fine grain clay. This because the fine grain has good binding properties and assist the formation of glassy phase which progressively fill the pore spaces and reduced the contraction of ceramic mass. Bernasconi et al. (2011) reported the similar finding where the low water absorption is given by the clay contains finer size of the quartz. Monteiro and Vieira (2004) note the high porosity of ceramic is related to high percentage of kaolinite in the clay mineral and low percentage of alkaline flux. What is more, the percentage of carbonate which more than 10% will contribute to high porosity (Sidjanin, Ranogajec, Rajnovic & Molnar, 2007).

2.5.3.2 Mechanical properties

This subchapter present the mechanical properties of green and fired product.

(a) Fired strength

Dowling (1999) defines strength as the stress required to cause a fracture or deformation on the material. Both the fracture and deformation are sensitive to rate of loading, defects and firing temperature (Hosford, 2010). The properties of ceramic are nonductile and brittle (Kuhn, Medlin & Committee, 2000). In many circumstances, the compressive strength in ceramic is higher than tensile strength (Higgins, 1994).

Sidjanin et al. (2007) note the mechanical properties of clay roof tiles are influenced by the mineral composition in clay and firing temperature. A series of chemical reaction has occurred in clay during firing, thus make it permanently hard, durable and resisting to weathering (Karaman et al., 2006). Monteiro and Vieira (2004) states that the strength sometimes drop at certain elevated temperature, due to the presence of 'black core', a defect in fired clay body. They further mention the black core is formed due to the reaction of remaining carbon in incomplete organic combustion with hematite.

Wachtman and Cannon (2009) note the common method to test the strength of ceramic is flexural test. Flexural strength or also known as modulus of rupture is defined as the maximum transverse breaking stress applied under specified condition, which a material will withstand before fracture (Dodd and Murfin, 1994). Wachtman and Cannon (2009) note the weaknesses of flexural test is the non-uniform distribution of stress. They add, if plastic deformation occurs, it will change with the increasing of strain.

Figure 2.13 presents the method applied for flexural strength. Kalpakjian and Schmid (2009) describe the load is applied vertically above the specimen, either at one point or two points. In comparison, the maximum bending moment only occurs at the centre of sample of three-points bending (Figure 2.13a) while the constant maximum bending moment is occurred in the four-points bending (Figure 2.13b). The lower surface of the specimens bear tensile strength while the upper surface will incur compressive strength (Kalpakjian & Schmid, 2009).

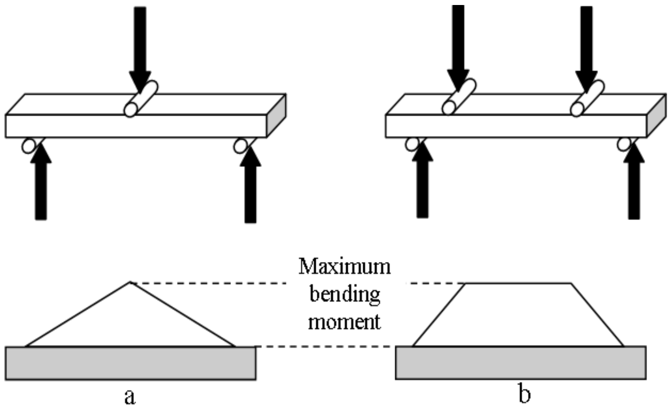

Figure 2.13: Three-points bending test (a) and four-points bending test (b)
Source: Kalpakjian & Schmid (2009)

Monteiro and Vieira (2004) note ceramic that fired at temperature above 1000°C has lower porosity due to the formation of liquid phase. They further state that the compressive strength also decreases and the formation of crack in the fired clay is reduces. Taskiran, Demirkol & Capoglu (2005) describes the high crystallinity of anorthite in the body of clay will contribute to the high strength of fired clay. Besides, the particle size distribution also affecting the strength of ceramic. Stathis et al. (2004) note the greater mechanical strength is obtained if the clay has optimum particle size distribution of quartz, which in the range of 5 to 20 µm. In addition, the strength of ceramic is also influence by the production method and load direction of bricks as noted by Karaman et al. (2006).

(b) Green and dry strength

According to Kogel et al. (2006), the green strength is defined as the strength of clay material in the wet or plastic state. They further mention that the strength of the clay after dried is known as dry strength. They note both green and dry strength are vital properties of clay because most of the structural clay product should be strong enough to maintain their shape. In fact, ceramic is a material that sensitive to the surrounding atmosphere during drying (Mujumdar, 1995). Brosnan and Robinson (2003) note the major source of defects in the production of most ceramic products is excessive drying shrinkage during drying. They further state the evaporation of water that takes place at the surface green product during drying will make its exterior part is placed in tension and initiated the crack to the green body.

The curve of graph shrinkage against firing temperature depicts the sensitivity of clay tiles to firing process as noted by Ducman, Škapin, Radeka, & Ranogajec (2011) (2011). They further state that if the slope is very steep, any minimal changes in firing temperature will contribute to high shrinkage, which may contribute to the problem in manufacture such as dimension variation in the product. In addition, the difference in the thickness of green pieces of ceramic will attribute to the cracking, which owing to the formation of cracking force caused by the difference shrinkage between the thick and thin sections (Brosnan & Robinson, 2003). The presence of quartz in the clay will prevent the formation of shrinking, cracking and warping of green bricks thus produces greater uniform shape of bricks as stated by Manoharan et al. (2011).

2.6 Quality of Clay Roof Tile

According to Chandra (2001), the term ‘quality’ refers to customer satisfaction, fit for their purposed, and meet the requirement. He further mentions that the unavoidable variation in the dimension of length, thickness, strength is contribute by the manufacturing faults including machines, tools raw materials and human operators. Therefore, the quality control during manufacturing process is an important factor in ensuring the quality of output. According to AC180:2012, the clay roof tiles need to be manufactured under a quality control and compliance with standard requirement so that it will fit to its particular designed which to ensure right installation and water flows.

2.6.1 Physical properties

This subchapter presents the quality measurement of physical properties of ceramic including dimension, surface and water absorption as specified by standards.

2.6.1.1 Quality of dimension

According to AC180:2012, the dimensional accuracy is important in ensuring the uniform and tight installation of tiles in the roof frame is achieved. The dimensional accuracy includes the length, thickness and width and the definition of this term is shown in the Table 2.8. According to BS EN 14411:2006 (Table F.1), the tolerance deviation of both width and length of ceramic tile is ±2.0 % while the thickness is ±10.0 % of the value declared by the manufacturer.

Table 2.8: Definition of length, thickness and width

Terms	Definition
Length	The maximum dimension of the tile measured parallel to the water channels or perpendicular to eave of the roof
Thickness	A measurement of the cross section of the tile made perpendicular to its surface
Width	The maximum dimension of the tile measured perpendicular to the length

Source: ASTM (C43)

2.6.1.2 Quality of surface

EN 14411:2006 stated that in obtaining the good quality of ceramic tiles, 95 % of its surface shall be free from visible defects which would impair the appearance of a major area of tiles. ASTM C1167-03 describes good quality of tile shall be free of defects, deficiencies or bloating, because it would interfere the proper laying of tiles. Table 2.9 shows a few types of surface defect and its definition.

Table 2.9: Surface defect and its definition

Surface defect	Description
Cracks	Any fracture in the body of the tile visible on the face or the back or both
Unevenness	An unintentional depression in the surface of a tile or a glaze
Pin hole	Tiny pit in the surface of a glazed tile
Chip	Fragment broken off from edges, corners or surface of a tile
Rough edge	An unintentional irregularity along the edge of a tile

Source: BS EN ISO 10545-2:1997

2.6.1.3 Water absorption

Table 2.10 shows the percentage of water absorption and the characteristic of each group. The ceramic tiles that has less than or equal to 3% water absorption are considered as good product (BSEN 14411:2006).

Table 2.10: Classification of ceramic tiles according to water absorption

Group	Water Absorption (E)	Description
Group I	$\leq 3\%$	Low water absorption
Group II	$3\% < E \leq 10\%$	Medium water absorption
Group III	$> 10\%$	High water absorption

Source: Adapted from BS EN 14411:2006

2.6.2 Mechanical properties

Table 2.11 shows the definitions of component in the mechanical properties of ceramic as explained by BS EN 1304:2005. This section will describes the modulus or rupture or also know as flexural strength of ceramic.

Table 2.11: Terms for mechanical properties and its definition

Terms	Definition
Breaking load	Force, expressed in newtons, necessary to cause the test specimen to break, as read from the pressure gauge
Breaking strength	Force, expressed in newtons, obtained by multiplying the breaking load by the ratio (span between supports rods)/(width of the test specimen)
Modulus of rupture	Quantity, expressed in newtons per square millimetre, obtained by dividing the calculated breaking strength by the square of the minimum thickness along the broken edge

Source: BS EN ISO 10545-4: 1997

2.6.2.1 Flexural strength

BS EN 14411:2006 classified the minimum requirement for flexural strength of ceramic tiles is classified according to its percentage of water absorption. Table 2.12 shows the group of water absorption its minimum requirement for flexural strength.

Table 2.12: Minimum requirement of flexural strength of ceramic tiles

Group	Water Absorption (E)	Min. Flexural Strength (N/mm^2)
Group I	$0.5\% < E \leq 3\%$	23
Group II	$3\% < E \leq 6\%$	13
Group III	$6\% < E \leq 10\%$	9
Group IV	$E > 10\%$	8

Source: BS EN 14411:2006

The minimum requirement of bending strength for ceramic of tiles that has low water absorption is 23 N/mm^2. In addition, the range of bending strength for tile that has medium water absorption must is 9 to 13 N/mm^2 bending strength. On the other hand, the minimum of 8 N/mm^2 are required for tiles that have high water absorption. ASM describes that the typical range of flexural strength of roof tile is 8 to 15 MPa (Kuhn, Medlin & Committee, 2000).

2.7 Summary

Singgora tile forms a symbol of identity to Malaysian traditional architecture. The decline of the demand and industry of Singgora tiles is contributed by the changing in the housing style and the inferior quality of the product. There is lack of researches conducted in improving the quality of Singgora tiles.

Clay is a raw material to make Singgora tiles. The change in physical states of clay has affected their physical characteristic. There are several elements presence in the clay including the accessory mineral, impurities and clay mineral which affecting their physical and mechanical properties.

Singgora tiles are produce using the traditional method. The traditional production method of are includes the clay winning and preparation, forming the shape, drying and firing the green tiles. The selection of clay to make the product is important and the impurities in the clay must be removed. The clay is prepared by crushing, grinding, screening and mixing. The traditional method of forming the tiles is manually by hand with the use of mould. The drying process of green tiles is carrying out properly to prevent the tile warping out of shape. The green tiles are fired using the traditional kiln. The operation of traditional kiln is inefficient due to the poor control of firing cycle which yields a non-uniform quality of product.

There are many factors affecting the mechanical properties of ceramic such as firing temperature, firing time, filler grain size, water absorption, mineral composition of clay, shrinkage, shaping technique and so on. Firing conditions are the most important element which contributes to the quality of product. A good properties of ceramic is achieves when its strength and degree of vitrification is develops at high firing temperature.

Clay roof tiles need to be manufactured under a quality control and compliance with particular standard in order to ensure right installation and water flows. The dimension check is important to ensure the uniform and tight installation is achieved when the tiles is installed using specified method. In addition, the tiles should have good surface quality for the proper laying of tiles. The good quality of clay tiles has not more than 3 % of water absorption. The minimum requirement of flexural strength of clay roof tile is describes according to the percentage of water absorption. The typical flexural strength of roof tile is 8 to 15MPa. Figure 2.13 summarize the whole idea on the relation between clay, firing, ceramic and properties of ceramic.

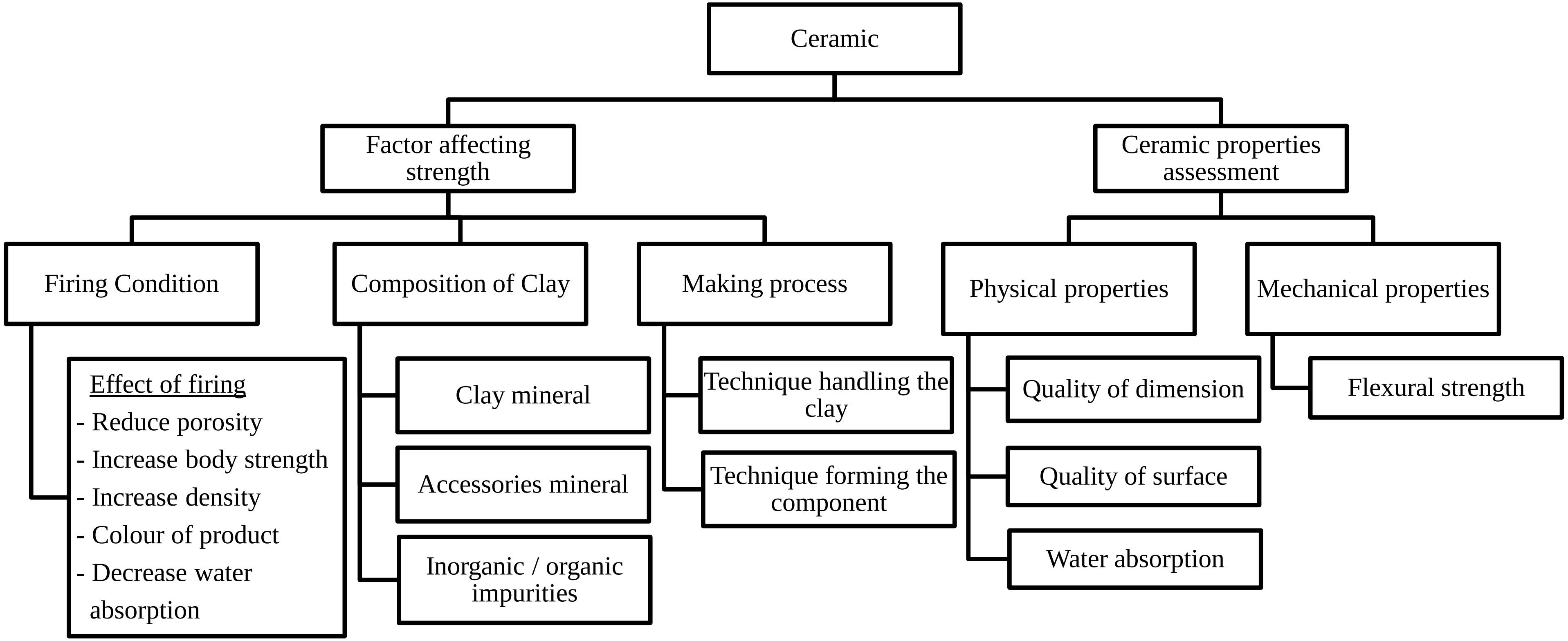

Figure 2.14: Factor affecting the strength of ceramic and the type of properties assessment

The focus of this research is to improve the quality of Singgora tiles produced by the local factory. As mention earlier, the factors that affecting the quality of clay tile product are quality of raw material, manufacturing process and firing condition. The effects of these three factors are already studied by other researchers. Studies have been conducted to improve the strength of existing factory product. However the result of these studies is less accurate due to the insufficient number of samples. Besides, there are also studies conducted on strength but not focusing on improving the quality of Singgora tiles based on the traditional method.

For the purpose of maintaining the authenticity of Singgora tiles which produced using traditional method, this study is only focusing on improvement of product quality through firing process which similar to the study conducted by Hidayah (2011) and Naeem (2012). The focus of improvement is only on the strength of Singgora tiles. The experiment was conducted according to the standard requirement as to obtain more reliable results. Others factors that contribute to low quality of Singgora tiles such as surface defect will not be considered as to maintain its handmade appearance. However, the suggestions for improvement of the production process which not giving any intervention to the traditional method of making Singgora tiles are also given in this study.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methods adopted to achieve the research objectives. The research methods used are case study and experimental work as shown in Figure 3.1. In the first stage, the case study is conducted to observe the manufacturing process of Singgora tiles in the factory. Next, the experimental work is carried out to evaluate the properties of factory product and to investigate the influence of firing temperature, firing time and impurities on the properties of Singgora tiles.

First Stage	Case Study (qualitative) - Observation on the manufacturing process of Singgora tiles
Second Stage	Experimental Work (quantitative) - Experiment 1: Testing the properties of existing factory product - Experiment 2: Testing the effect of firing temperature and firing time on the properties of Singgora tiles

Figure 3.1: The research methods

3.2 Case Study

O'Leary (2010, p. 174) defines a case study as "method of studying elements of the social through comprehensive description and analysis of a single situation or case". According to Gray (2004), the case studies not only describing a situation, but explore the ambiguous relationship between subject and issues, and trying to attribute causal relationships. An intrinsic case study is conducted if the researchers want to understand a particular case study in more detail (Chua, 2012). For the purpose of this study, the approach of intrinsic case studies is applied in order to gain an in-depth understanding of the factors behind the issue of low quality of Singgora tiles.

3.2.1 Observation on the manufacturing process of Singgora tiles

The field research method was conducted through an observation at the factory of Singgora tiles located at Beris Kubur Besar, Bachok, Kelantan (Figure 3.2). The purpose of the observation was to document the manufacturing process of Singgora tiles. Based on this observation, an inappropriate production methods and the type of defects that occurred on the product due to these mistakes are identified. The instruments used for observation were field journal, video recorder, checklist, camera, measuring tape and sketch book. The observation was carried out according to the common stages in manufacturing the clay product as shown in Figure 2.9.

Figure 3.2: The key plan of the factory.
Source: JUPEM (2004)

The clay winning and preparation were included type of clay used, selection of raw material, their location and the person who do the selection; either skilled or unskilled worker. In addition, the manner in which the clay is won or dug and transported to the factory was also observed. Next, the observation was focused on the method used to treat the excavated clay. Then, the forming method was observed to determine the traditional practice and equipment used to shape the Singgora tiles. In the next stage, the drying process was observed to identify the method and location to dry the green tiles. Finally, the firing process of Singgora tiles was observed. The data collected at this stage was included the method used to load the green tiles into the chamber of kiln, type of fuel used, duration of firing and both design and operation of the kiln. Other than making process, the equipment and tool that used to make Singgora tiles were also documented.

3.3 Experimental Works

There two types of experiment were conducted in this study. First, the experimental works to determine the properties of existing factory product (Experiment 1). Second, the experimental works to investigate the influence of impurities and firing conditions on the properties of Singgora tiles (Experiment 2).

3.3.1 Experiment 1: Testing factory product

Laboratory work was carried out to test the properties of Singgora tiles produced by existing factory. In this experiment, the test of surface quality, dimensional accuracy, percentage and type of impurities, grade of sand in clay, water absorption and flexural strength test were conducted.

3.3.1.1 Preparation of samples

The properties of factory product were tested in terms of green tiles and fired tiles. Fifteen pieces of green tiles were randomly collected from the factory. These green tiles had gone through the process of wedged, shaped and dried under the sun. The properties of them were determined by conducting the tests on the surface quality, and percentage and type of impurities. Thirty pieces of fired tiles were also randomly collected from the factory. These tiles were fired using traditional kiln. The fired tiles were subjected to the tests of surface quality, dimensional accuracy, water absorption and flexural strength. Table 3.1 shows the number of tested sample for each type of test. The number of samples used is according to the standard requirement.

Table 3.1: Number of samples for different type of test

Type of test	No of sample	
	Green tiles	Fired tiles
Surface quality	10	10
Dimensional accuracy	-	10
Percentage and type of impurities	5	-
Water absorption	-	5
Flexural strength	-	5
Total no. of sample	15	30

3.3.1.2 Surface quality test

The surface quality test was conducted to determine the defect of the product. This test was conducted on the both green and fired tiles.

(a) Green tiles

The apparatus used for the assessing the quality of tile surface were fluorescent lighting (6500 K colour temperature), measuring tape (Figure 3.3a) and light meter (Figure 3.3b).

The sample was divided into three parts; the hook, the body and the arrowhead (shaped tale) as shown in Figure 3.4. The samples were illuminated by fluorescent lighting with light intensity of 300 lx at the surface of the tiles. The surface of sample was viewed perpendicular with naked eyes at 1 m distance. The conditions of all parts particularly the defects were accordingly recorded. The percentage of defect was calculated based on the defective area.

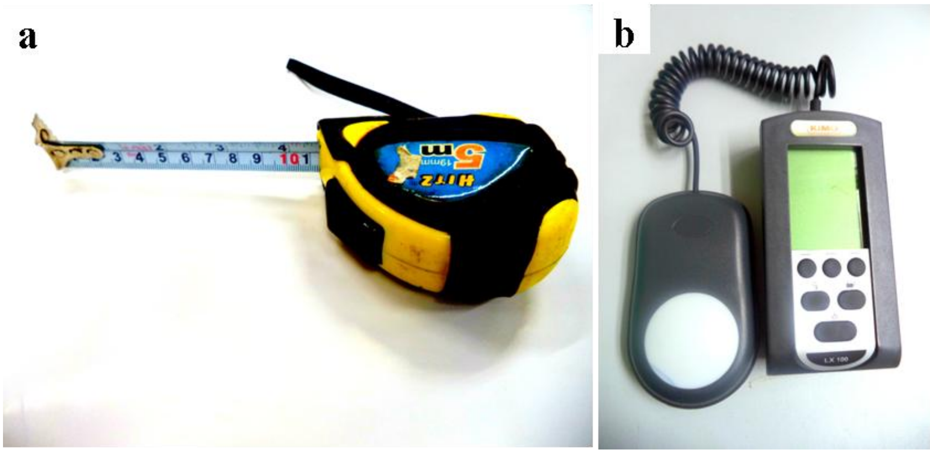

Figure 3.3: Measuring tape (a) and light meter (b).
Source: Field study (2013)

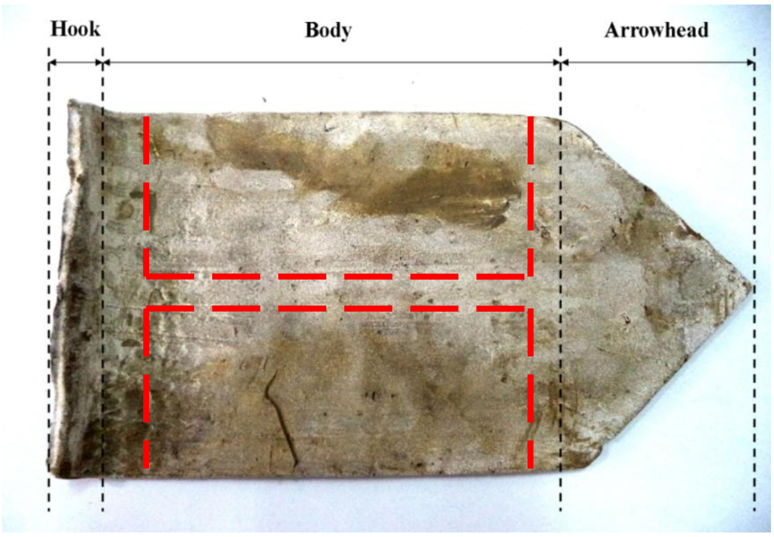

Figure 3.4: The body of green tile was divided into hook, body and arrowhead.
Source: Field study (2013)

(b) Fired tiles

The surface quality of fired tiles was tested according to the method describe in subsection 3.3.1.2(a). In addition, the surface of fired tiles was also observed with microscope Olympus SZX7 (Figure 3.5) as to get the better view of defect. This apparatus assists in capturing the image of fine defects such as coarse sand, coal and crack. All of the defects were observed at 0.8 x magnifications.

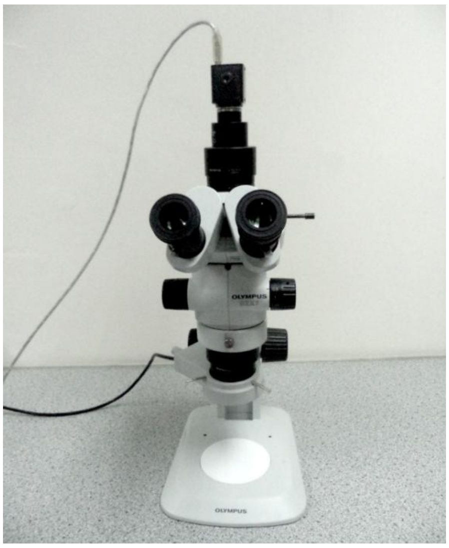

Figure 3.5: Microscope Olympus SZX7.
Source: Field study (2013)

3.3.1.3 Dimensional accuracy

The dimension test was conducted to determine the accuracy of length, width and thickness of Singgora tiles. The dimension of sample was measured at the body part of fired tiles. The apparatus used to measure the fired tiles were vernier calliper and micrometer. Figure 3.6 shows the reference lines to measure the samples.

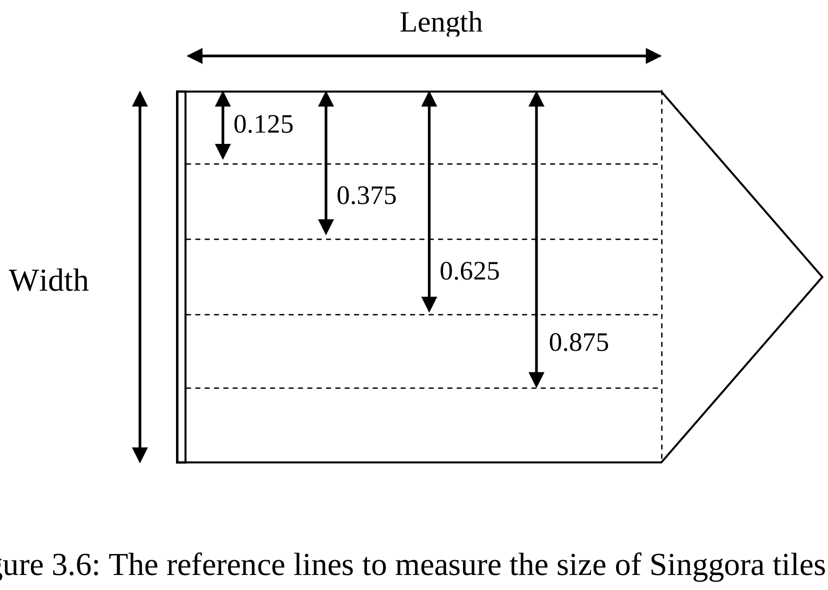

Figure 3.6: The reference lines to measure the size of Singgora tiles.
Source: Field study (2013)

The width of tiles was measured at a distance of 0.125, 0.375, 0.625 and 0.875 times the length of the samples which measured from the end of tiles. The thickness was measured at the thickest point on each line. The results were used to calculate the average dimension of length, width and thickness of Singgora tile.

3.3.1.4 Percentage and types of impurities

The test was conducted to determine the percentage and types of impurities that contain in a piece of green tile. The apparatus used in the experiment were digital balance, regular sieve (0.53 mm mesh), nested column of sieves with wire mesh cloth (5.00, 2.36, 1.18, 0.60, 0.53, 0.15 mm mesh) and mechanical shaker. The procedure for the test was as follows:

[1] The green tile was dried using oven Carbolite PF 30 located at Rintis Laboratory, Faculty of Engineering, University of Malaya (Figure 3.7a). The samples were dried at temperature 50 ºC for 2 hours. The low temperature for drying was used as to avoid the firing of light impurities such as paddy leave.

[2] After dried, the samples were weighed and dried again until two successive weighing at interval of 1 hour showed an increment of loss not greater than 0.1 % of the last previously determined weight of the sample. The last weighed data was recorded as W_t.

[3] Next, the samples were soaked in water for 24 hours.

[4] The samples which mixed with water were filtered using regular sieves.

[5] The impurities that stuck on the sieve were dried with oven at temperature 50 ºC for 2 hours.

[6] After dried, the grogs in the impurities were removed by hand. The remained impurities were weighed and the data was recorded as W_i.

[7] The percentage of impurities was calculated using the following equation:

$$Percentage\ of\ impurities: \frac{Weight\ of\ impurities\ (W_i)}{Weight\ of\ dried\ green\ tiles\ (W_t)}\ x\ 100$$

[8] Then, the dried impurities were sieved with nested column of sieves with wire mesh cloth and mechanical shaker to determine the percentage and types of impurities based on their size and the grade of sand (Figure 3.7b).

[9] The impurities that stuck at each size of mesh were weighed and the data was recorded as W_s. The percentage of impurities was calculated as follows:

$$Percentage\ of\ impurities\ based\ on\ size:$$

$$\frac{Weight\ of\ impurities\ at\ each\ mesh\ (W_s)}{Weight\ of\ impurities\ (W_i)}\ x\ 100$$

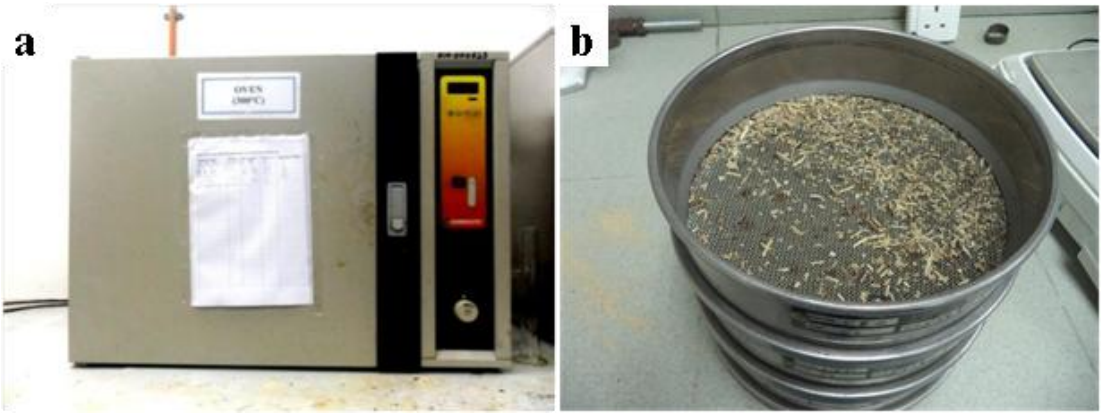

Figure 3.7: Oven Carbolite PF 30 (a) and nested column of wire mesh sieves (b).
Source: Field study (2013)

3.3.1.5 Water absorption

The porosity of Singgora tiles was determining using water absorption test. The apparatus used in the experiment were digital balance, heater (Figure 3.8a), thermometer and damp cloth. The body area of Singgora tiles were cut to a size of 110mm length and 70mm width using the cutter machine (Figure 3.8b).

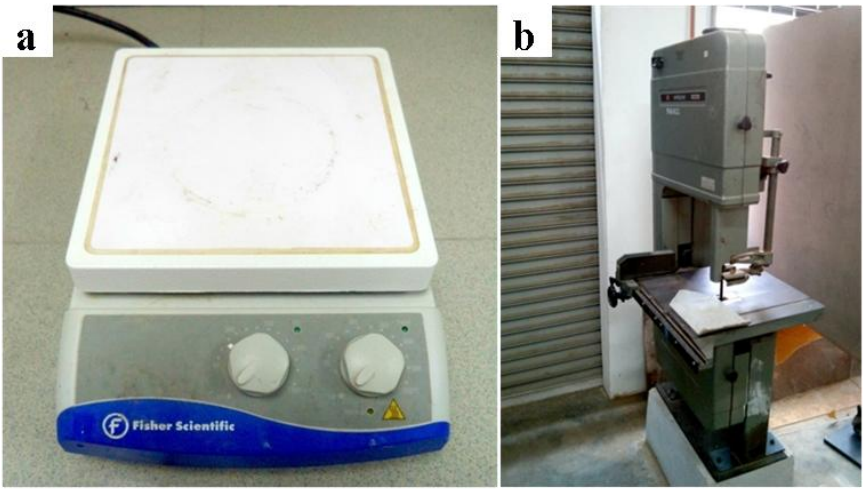

Figure 3.8: The heater (a) and cutter machine (b)
Source: Field study (2013)

The samples were dried to constant weight with oven. The drying process was conducted according to ASTM C 67:98a. The temperature was increased by the increment of 5 °C/min maintained constant at temperature 100 °C for 24 hours. Then, the sample was weighed and heated again at the same temperature until constant mass was reached. The constant mass was obtained when two successive weighing at interval of 2 hours shows an increment of loss not greater than 0.2 % of the last previously determined weight of the sample. The total drying time was 28 hours. Figure 3.9a shows the arrangement of samples inside the oven during drying process. The samples were test in less than 2 hours after reached the room temperature.

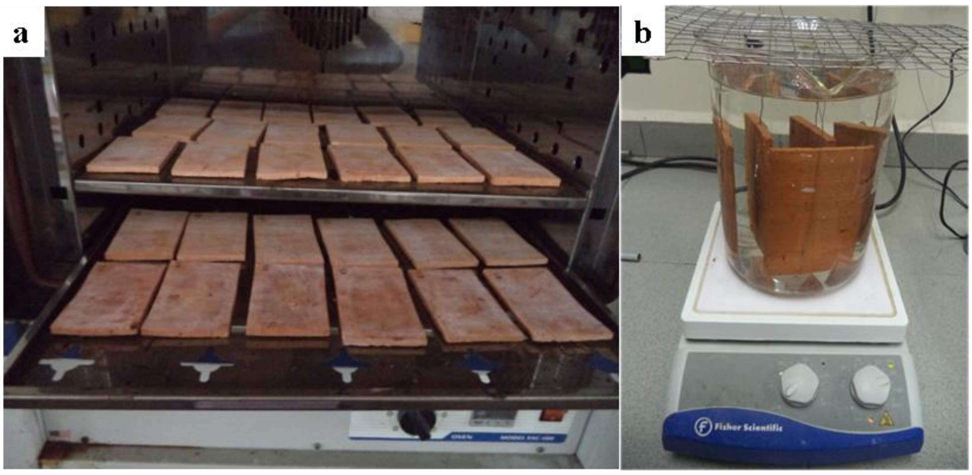

Figure 3.9: Samples inside the oven (a) and samples immersed in water (b).
Source: Field study (2013)

The procedure for conducting the water absorption test was as follows:

[1] The samples were weighed with digital balance and recorded as dry weight ($W_{d)}$.

[2] Next, the samples were tied with a steel wire and hang on steel net.

[3] Then, tied samples were immersed in a beaker that contained distilled water. The sample was completely immersed and did not touch the bottom of beaker and other samples (Figure 3.9b).

[4] The container was heated with heater and soaked for two hours at boiling point. The thermometer was used to check the temperature of boiling water.

[5] After that, the heater was turned off and samples were left immersed in water for four hours.

[6] Excess water in the surface of sample was wiped out with damp cloth once it was removed from the beaker.

[7] The samples were weighed and recorded as wet weight (W_w).

The percentage of water absorption was calculated using the following formula;

$$Absorsorption, \% = \frac{W_w - W_d}{W_d} \; x \; 100$$

3.3.1.6 Flexural strength

The strength of Singgora tiles were determines using flexural test. It was conducted according to the procedure described in ASTM C 1167-03. The test was carried out at Fundamental Sciences Material Laboratory Faculty of Engineering, University of Malaya. The apparatus used in the experiment was universal testing machine; Instron 4469 (Figure 3.10a), vernier calliper and marker.

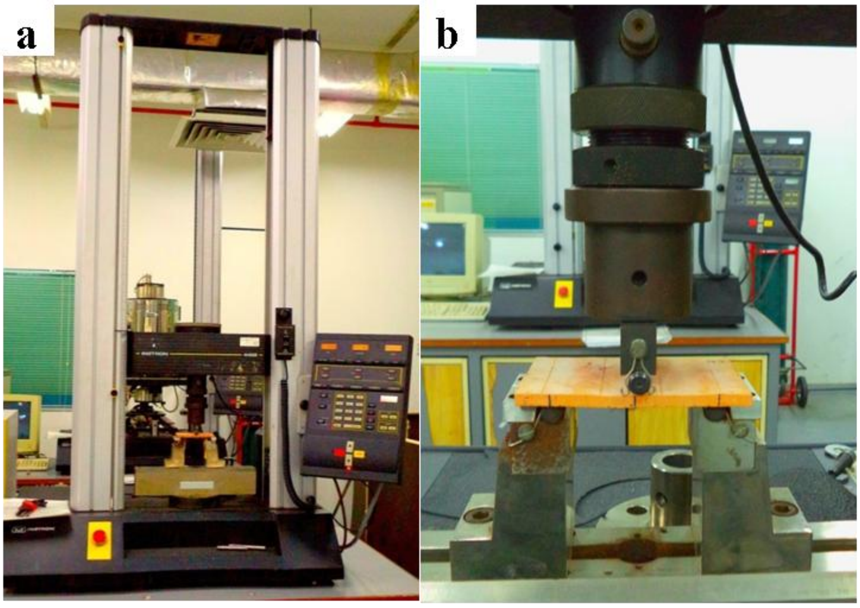

Figure 3.10: Machine Instron 4469 (a) and the setting of sample on the machine (b)
Source: Field study (2013)

The fired body of Singgora tiles were cut to a dimension of 110mm x 70mm using the cutter machine. The test was started by measuring the dimensions of each sample with vernier calliper. Next, the drying method was used to prepare the samples for flexural test which according to method specified by ASTM C 67:98a.

The samples were subjected to flexural test in less than 2 hours after reached the room temperature. The span size of testing machine was 75 mm which based on the distance between the horizontal tiling battens in the roof frame as described by Zulkifli (1996). The speed of the moved head of the testing machine was 0.2 mm/min, which similar to a study conducted by Sidjanin et al. (2007). Before the test was conducted, the centre of sample was determined with vernier calliper and it was marked with permanent marker.

The flexural test was started by placing the sample on the two support rods with the proper surface of the tiles uppermost (Figure 3.10b). The central cylindrical rod was positioned at the centre between the supports rods. It was manually adjusted until slightly touched the centre of sample surface. The dial test-indicator was set to zero before the test was started. Then, the test was run and automatically stopped at rupture. A typical flexural strength test result for Singgora tiles is shown in Figure 3.12.

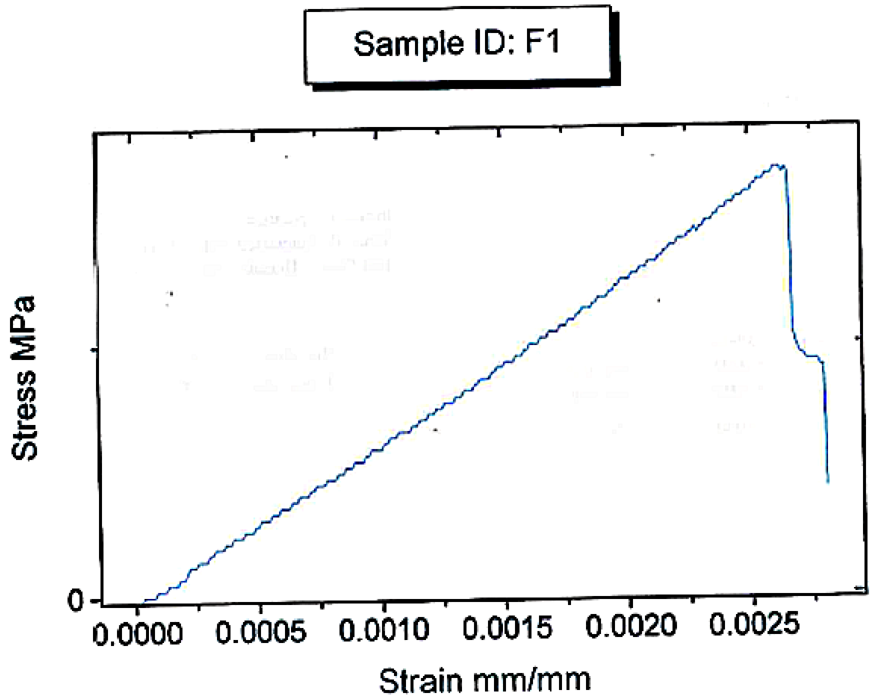

Figure 3.11: The typical flexural strength result
Source: Field study (2013)

The result of flexural strength given by machine Instron 4469 was less accurate. Therefore, the flexural strength of tiles of each sample was manually calculated as follows:

$$Flexural\ strength, S = 3W(\frac{I}{2})/bd^2$$

Where:

S = flexure strength of the sample; W= maximum load indicated by the testing machine, N; I= span size, mm; b= net width, mm; d= depth, mm

The standard variation of samples was calculated using the following equation:

Standard deviation, σ

$$= \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2}$$

Where:

Σ = standard deviation; N = number of sample; $\bar{X}$ = mean value of flexural strength; X_i = flexural strength of each sample

3.3.2 Experiment 2: Firing and testing the Singgora tiles

Van Vlack (1964) noted that the strength of ceramic is inversely proportional with porosity and particle size. He further states both of these factors are controlled through firing, which aimed to produce an appropriate microstructure. This statement is also supports by Lynch (1994), which the firing process is the most important stage in the process of making clay product. For the purpose of this study, the approach of firing process is taken to improve the quality of Singgora tiles. The Experiment 2 was conducted by:

1) Firing the green tiles at various temperatures and times
2) Testing the properties of fired tiles

3.3.2.1 Preparation of samples

100 pieces of green tiles were randomly collected in the factory and fired at various temperatures and times in the laboratory. In fact, only 75 pieces of green tiles are required for this experiment. However, extra green tiles were taken because the selection of green tiles was carried out so that only the best quality of samples is fired and tested. The surface quality assessment was conducted on the green tiles to select the

best samples. The selected green tiles was cut, labelled and dried. One hundred fifty samples were prepared to be fired at various conditions.

(a) Surface quality of samples

The apparatus and procedure of this experiment were according to the method adopted in section 3.3.1.2(a). For the purpose of firing, the body of green tile was used as a sample. Only the samples that had at least 95% free from visible defect were used to be fired and tested.

(b) Cut the samples

75 pieces of selected green tiles were cut into the dimension of 110 mm length and 70 mm width using cutter machine. This selected dimension was designed based on ASTM C1167-03:2003, where the shorter span for transverse breaking are not prohibit, but must not less than 2/3 of the length of tile. Besides, this size can fit the furnace chamber and the central cylindrical rod of flexural testing machine. The cut area of green tiles is shown by the dotted red line in Figure 3.5. Two pieces of sample were obtained from each piece of green tile. The total number of samples that prepared was 150 pieces.

(c) Labelled the samples

The samples were properly labelled to differentiate their firing condition. Table 3.2 shows the label of samples.

Table 3.2: The label of sample and its firing conditions

Label	Description	No of sample
A	Samples fired at temperature 850 °C for 4 hours	15
B	Samples fired at temperature 900 °C for 4 hours	15
C	Samples fired at temperature 950 °C for 4 hours	15
D	Samples fired at temperature 1010 °C for 4 hours	15
E	Samples fired at temperature 1050 °C for 4 hours	15
F	Samples fired at temperature 900 °C for 6 hours	15
G	Samples fired at temperature 900 °C for 8 hours	15
H	Samples fired at temperature 900 °C for 10 hours	15
J	Samples fired at temperature 900 °C for 12 hours	15
K	Samples fired at temperature 900 °C for 14 hours	15
	Total no. of sample (piece)	150

(d) Dried the samples

The samples were heated with oven to drive off the water inside the body before subjected to the main firing. Figure 3.12 shows the graph of firing temperature against firing time. The drying process was conducted according to ASTM C 67:98a.

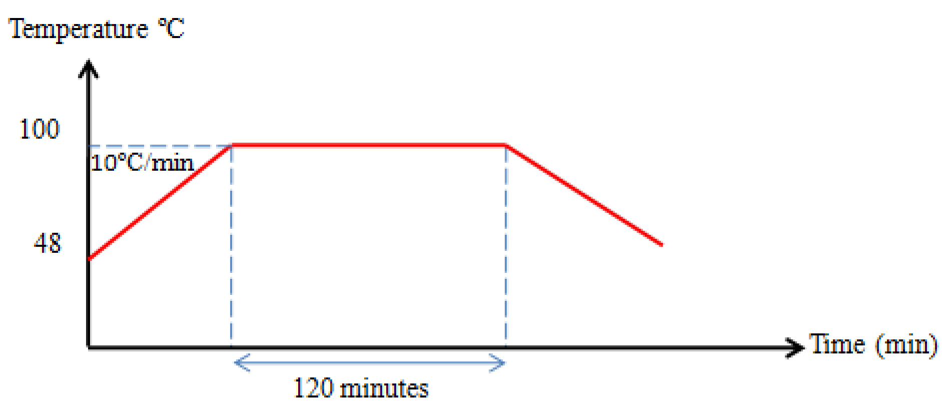

Figure 3.12: The drying phase of green tiles.

3.3.2.2 Firing the green tiles at various temperatures and times

The samples were fired at preference firing conditions as described in Table 3.1 in less than one hour after dried in the oven. The main firing process was conducted at Ceramic Laboratory, Faculty of Engineering, University of Malaya. The apparatus used in this experiment was Lenton Furnace (Figure 3.13a). The arrangement of the samples in the furnace chamber is shown in the Figure 3.13b. Fifteen samples were fired at each firing condition as shown in Table 3.2.

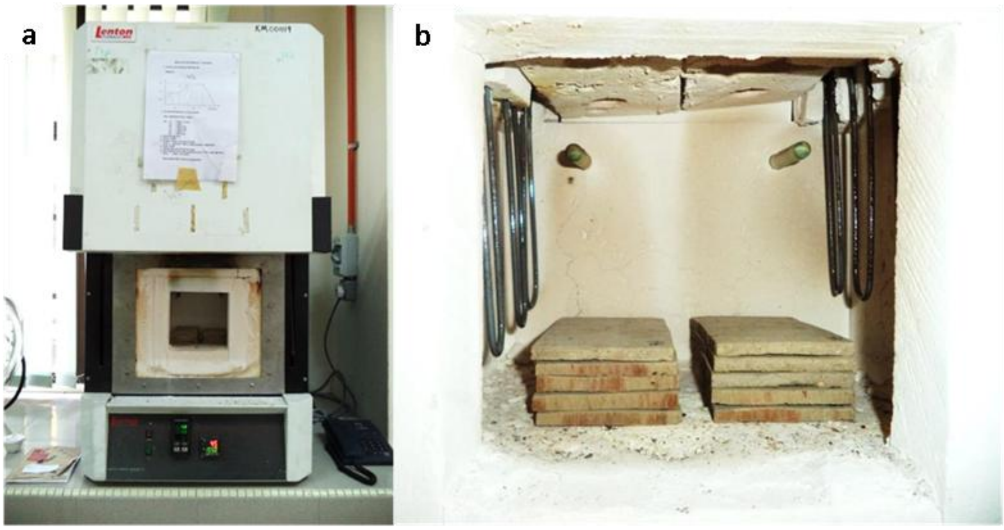

Figure 3.13: Lenton Furnace (a) and samples inside the chamber furnace (b).
Source: Field study (2013)

There were two conditions of firing process in the experiment;

[1] Fired at various temperature

The samples were fired at temperature 850°C, 900°C, 950°C, 1010°C and 1050°C for four hours. According to Fraser (2000), the burning of organic matter is occurred at temperature 900°C and upwards. However, the firing temperature between 850°C to 1050°C was used in this study in order to measure the effect of impurities on the properties of tiles.

[2] Fired at various time

The samples were fired at temperature 900°C for 4, 6, 8, 10, 12 and 14 hours. This selected temperature was similar to the minimum range of highest temperature achieved in the burning zone of traditional kiln (Mason and Hill, 1999). The selected firing time was start at 6 hours which according to the finding from the experiment conducted by Hidayah (2011) and Naeem (2012). According to Figure 2.6, a pronounced increment of strength is observed at 3 to 6 hours firing time. The strength shows a small increment when fired at 8 hours. It is expected that the strength of tile fired for 5 hours will be less than the standard requirement which is 8N/mm^2. Therefore, this experiment was started at 6 hours firing time with 2 hours interval on further heating. This experiment also repeats the study conducted by Naeem (2012) as the result given by him is less accurate due to the insufficient number of sample.

Figure 3.14 shows the graph of firing temperature versus time. The 'y' represents the preference maximum temperature while 'x' is the maximum time. The rate of firing was 10 °C/min. The sample was allowed to cool inside the furnace for 12 hours.

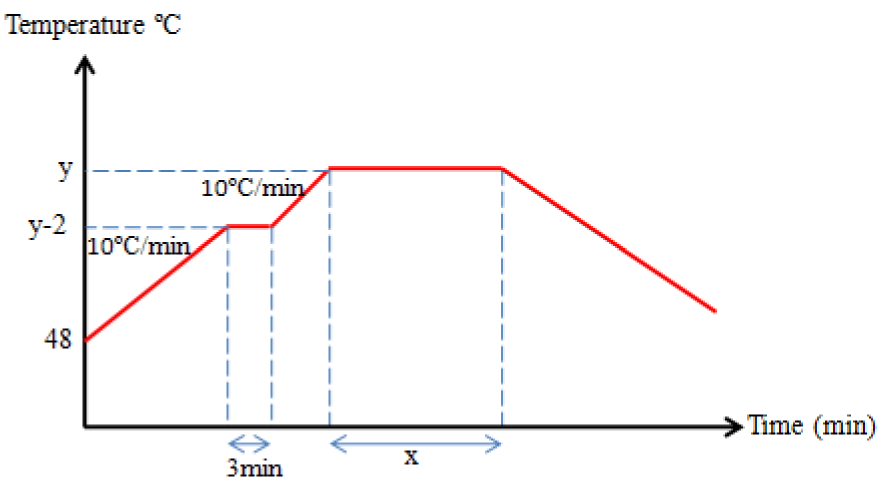

Figure 3.14: Graph maximum firing temperature versus maximum firing time.

The samples that fired at various firing temperature and time were subject to water absorption and flexural strength test.

3.3.2.3 Water absorption test

The apparatus and procedure of experiment were according to the method adopted in subsection 3.3.1.5. Seven samples from each firing condition were tested in this experiment. The average value of water absorption was only considered five minimum results from each preference firing condition.

3.3.2.4 Flexural strength test

The apparatus and procedure of experiment were according to the method adopted in subsection 3.3.1.6. Eight samples from each firing condition were tested in this experiment. The average value of flexural strength was only considered five minimum results from each preference firing condition.

3.4 Summary

As a summary, there are two methods of data collection used in this study consist of case study and experimental works.

(a) Case Study

The case study was conducted to document the manufacturing process of Singgora tiles trough the observation at the factory. The observation also identified the inappropriate production methods and the type of defects that occur on the product due to these mistakes. The sequence of observation at the factory was according to the regular production stage of clay product.

(b) The experimental work

The experimental works was conducted to determine the properties of factory product and properties of tiles which fired at various conditions at the laboratory. Table 3.3 shows the summary of both experimental works.

Table 3.3: The description of experimental works

	Experiment 1	Experiment 2
Samples collection	Twenty pieces of both the green and fired tiles collected at the factory	Hundred pieces of green tiles collected at the factory
Firing equipment	Traditional kiln	Electrical furnace
Preparation of samples	• The sample ware divided into three parts for the purpose of surface quality test and dimensional accuracy test. • Ten pieces of fired tiles were cut to smaller size for the purpose of water absorption and flexural strength test.	• Selection of best quality of green tiles • Cut the green tiles • Dried the samples • Firing the samples at various temperatures and times
Testing the properties of green tiles	• Surface quality • Percentage and types of impurities • Grade of sand	• Surface quality (to select the best samples to be fired)
Testing the properties of fired tiles	• Surface quality • Dimensional accuracy • Water absorption • Flexural strength	• Dimensional accuracy (for the purpose of flexural strength) • Water absorption • Flexural strength

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of case study and experimental work. The finding from case study is the documentation of manufacturing process. The manufacturing process includes the method adopted by the manufacturer to produce Singgora tiles, the inappropriate production process and defects that occur on the product due to these mistakes. The results of experimental works are comprises of the properties of existing factory product and properties of tiles which fired at various temperatures and times.

4.2 The Manufacturing Process of Singgora Tiles

The manufacturing process of Singgora tiles is divided into the clay winning and preparation, forming the tiles, drying the green tiles and firing the green tiles as well as the equipment and tool.

4.2.1 Clay winning and preparation

Clay is the basic raw material to produce Singgora tiles. The type of clay used to make Singgora tiles is beach ridges interspersed with swales (Bris) which predominantly found in East Coast of Malaysia. This clay is available in the paddy fields along the Kemasin River as shown in Figure 4.1. The area at the stagnant water shows the former excavated area. Study found that there is no selection of raw material is carried out during digging the clay and the excavation works is carried out by unskilled worker. The clay is randomly excavated with bulldozer to a depth of 1 m from the surface of paddy field. Therefore, the humus and organic material deposited at the surface of the soil are also taken.

Figure 4.1: The bris soil in the the paddy field
Source: Field study (2013)

After excavated, the lorry is used for transporting the clay to the factory. The clay is stored abundantly in the workshop as shown in Figure 4.2. The colour of clay was brownish grey. The observation founds that the clay was composed of numerous impurities such as rotten wood, coal, course sand, dry leave, bark and stone.

After storage, the clay is further mixed with the water and grogs. This mixing work is carried out by the treading of men until a uniform mud is obtained (Figure 4.3). The study discovered that the low quality of the product was closely related to the method adopted in the preparation of the raw material. There is no treatment process carried out to remove the impurities that mixed with the clay. Therefore, the bad quality of clay is used to make Singgora tiles. According to West and UNIDO (1969), to avoid the goods from being misshapen, all foreign material, including stone, timber and large roots, can be removed by hand when the clay dries.

Figure 4.2: The clay was stored in the front area of factory
Source: Field study (2013)

Figure 4.3: The clay is kneaded with foot
Source: Field study (2013)

In fact, the good practices in preparing the high quality raw material are the clay is dried, crushed and sieved before being mixed with water (Shafiee & Sulaiman, 1992; Shippen, 2005). Greater quality control while preparing the clay is the key to produce a better and more uniform quality of product (West & Organization, 1969). It will make the clay easier to shape, give a smoother tile surface as well adding strength to the dry green tiles and fired products.

4.2.2 Forming the tiles

The observation found that the method of shaping the tiles also contributes to the defects on the product. In this traditional process of tile making, the mould is placed down over the ground and its surface is liberally sprinkled with rice husk ash for easy release. A lump of clay is thrown by hand into a frame mould and compacted into the mould by foot as shown in Figure 4.4. It is kneaded in a standing position, thus the clay is less directing into the corners of mould. As a result, a non-uniform product was produced.

Figure 4.4: The clay is kneaded with foot above the surface of wooden mould
Source: Field study (2013)

Next, the wet green tiles are put on the pallet. Thirty pieces of green tiles are stacked on it. This practice has contributed to the early defects on the surface of the tiles. Relatively thin dimension of thickness caused the green tiles to easily deform. According to Figure 4.5, the green tiles at the bottom layer have greater flat shape as placed on a flat base compared to the top layer. In addition, it is also shows the non-uniformed thickness of the green tiles.

Figure 4.5: The back area of green tiles is thicker than front
Source: Field study (2013)

The observation found that the pallets are poorly stored, resting on the ground and some of them are covered with cloth (Figure 4.6a). They are exposed to damage by livestock such as chickens, cats and goats, thus leaving defects on the tiles' surface as shown in Figure 4.6b. In fact, the wet tiles should have been placed individually in the rack to protect the freshly made tiles (Selker & Chikders, 1986).

4.2.3 Drying the tiles

The study also discovered that there is no designated area to dry the wet green tiles. The place that is used to dry the pieces of green tiles is an area with an uneven ground surface covered by patches of grass, gravel and sand as shown in Figure 4.7. This drying is located next to the factory. This open drying ground is accessible to livestock and children who roam freely in the surrounding area, and they sometimes trample on the tiles. It was also observed that small stones, grass, and sand were stuck to the base of the green tiles.

Figure 4.6: The green tiles are covered with cloth (a) and footprint by livestock (b)
Source: Field study (2013)

Figure 4.7: The tiles were dried naturally outdoors and laid on the ground
Source: Field study (2013)

The end part of the tiles was bent upright (Figure 4.8) to form the hook during drying and this led to the area of bending being cracked.

Figure 4.8: The end area of body tile was bent upright to form the hook
Source: Field study (2013)

The drying time is varied from one batch of green tiles to the next, depending on the weather. Normally, in hot sun, the green tiles are dried for two hours. It was observed that the tiles were dried without any repositioning thus creating a non-uniform dried surface. As a result, the loss of moisture only occurred on one side of the tile. This practice causes the surface facing the ground to be warped, cracked and chipped, owing to the fact that it has not gone through the appropriate drying process.

According to West and UNIDO (1969), it is crucial to evenly dry the surface of the tiles as a smaller moisture gradient between the surface and the centre of the dry green tiles will reduce the chances of cracking. They further mention that the drying process should be carried out properly because it not only eliminates water to ease firing but also makes the tiles stiff enough to be set into the kiln. This drying of the clay will prevent the tiles from twisting and cracking in the kiln (Lynch, 1994).

After dried, the green tiles are loaded onto a barrow and transferred to the factory as shown in Figure 4.9. The observation discovered that many tiles broke due to this transportation process.

Figure 4.9: The dry green tiles are stacks onto a barrow
Source: Field study (2013)

Before stored, the uneven surface of green tile is flattening using wooden paddle (Figure 4.10). Ten pieces of unbaked tiles is stacked close together and each surface area is knocked. This served to break the tiles as it disturbed and broke the bonding between the particles of plastic clay.

Figure 4.10: Each side of dry green tiles are banging with paddle
Source: Field study (2013)

The green tiles were stacked without the use of rack in the working area of the factory, and only bamboo and wood are used to prevent them from collapses (Figure 4.11). All dry green tiles will be fired once their quantity reaches approximately forty thousand pieces. This situation will let the dried green tiles to readsorb the moisture in an ambient atmosphere as mentioned by Brosnan & Robinson (2003). They further state the moist green tiles owing to moisture adsorption will lead to expansion of open cracks owing to steam spallation when they are inserted directly into the kiln. Therefore, the green tiles should undergone the drying process again to eliminate the moisture before being subject to firing process.

Figure 4.11: The dried green tiles were stacked without rack in the factory
Source: Field study (2013)

4.2.4 Firing the green tiles

In the traditional process of firing the Singgora tiles, the green tiles are loaded by hand with the help of twelve workers. Six of them handed the green tiles over (Figure 4.12a) to the worker which stayed inside the chamber of kiln (Figure 4.12b).

Figure 4.12: The workers inside (a) and outside (b) the kiln
Source: Field study (2013)

The green tiles are loaded from above of the kiln, since no door is constructed in the kiln wall. The ladder is used by the worker to go into the kiln chamber. The green tiles is arranged alternately, which start from the edge side of the kiln as shown in the Figure 4.13. It is closely stacked and broken Singgora tiles are used to fill the gaps between them.

Figure 4.13: The arrangement of green Singgora tiles inside the kiln’s chamber
Source: Field study (2013)

The method used to set the second layer of green tiles is stepped on the first layer, and it is continued until reach the final layer. This loading process is taken eight hours to finish. It was observed that a lot of green tiles were broke during the loading process due to the imposed load by the worker and ladder.

Forty thousand pieces of green tiles were stacked in ten layers in the kiln chamber with small gaps between the layers. This created uneven heat distribution as the kiln was overloaded with tiles. According to Grimmer et al. (1993), the uneven circulation and distribution of heat yielded a multi-colour effect and various strength of product. They further mention that a lot of tiles are broken in the lower part of kiln due to the overloading from upper layer of tiles. The excessive loading may cause the occurrence of deformation on the green products before the firing began (Warren, 1999).

The top layer of green tiles is covered with closely packed burnt bricks (Figure 4.14a) without mortar, to trap the heat inside the chamber of the kiln. Before the firing is started, the fire-box is cleaned by removing the ash of fuel inside the fire-mouth (Figure 4.14b). The fire is ignited with dried rubber wood as a fuel. The slow heating using light fire is used at the beginning of firing which takes about seven to eight days, depending on weather.

Figure 4.14: Bricks on the top of green tiles (a). The ash is removed using shovel (b)
Source: Field study (2013)

The firing process is continued using large fire when white powder like chalk appeared on the surface of tiles. This phenomenon is known as efflorescence, where the crystalline deposit of soluble salts on the surface of tiles owing to water migrating within the tiles and evaporating on the surface (BS EN 1304:2005). The full fire used the same fuel as light fire and the maximum temperature is held for three days to ensure the uniformity of heat throughout the chamber. The yellowish green colour of fire indicates the kiln has reached the maximum temperature. It was observed that the hot gases rose through the tiles was exit at the top. Therefore, the arrangement of brick on top of the green tiles is an inappropriate method to trap the heat.

The cooling stage is allowed to take place at the natural rate and both fire-mouth is block up using clay brick and plastered with the mixture of sand, wooden ash and water as shown in Figure 4.15.

Figure 4.15: The two fire holes were blocked up to allow the kiln cool naturally
Source: Field study (2013)

The fired tiles are left to cool inside the kiln for one week before unloaded. The finished products are shown in the Figure 4.16a. The fired tiles are flicked to test the quality of them. The shrill sound is produced by good quality product and vice versa. According to the worker, the low quality of tiles was normally produced in the rainy season due to wet soil condition. The colour and quality of tile that fired in the top, middle and bottom of the kiln chamber are different. Under-fired tiles are always found at the kiln’s top where heat losses are greatest, and over-fired tiles are found in areas of kiln’s bottom. Figure 4.16b shows the tiles after unloaded from the kiln and arranged at the edge of factory.

Figure 4.16: Singgora tiles in the kiln (a) and in the edged of factory (b)
Source: Field study (2013)

4.2.5 Equipment

The defects of Singgora tiles are also contribute by the fault of tools and equipment such as wooden mould, bow-wire and kiln.

(a) Wooden mould

In terms of equipment, the uniformity and maintenance of traditional tools are not given enough emphasis. It was found that size of mould that used to shape the tiles is non-uniform. Table 4.1 shows the dimension of the mould.

Table 4.1: Variable size of mould (refer Figure 4.17)

Equipment	Dimension (mm)			
	Length (a)	Length (b)	Width (c)	Thickness
Mould 1	302	221	164	8
Mould 2	320	225	165	7
Mould 3	320	234	164	5

The non-uniformity among the size of mould has resulting in a variation of thickness of product between 5 and 8 mm. As a result, the quality of the output is different, as the thicker tiles normally possess better strength. In addition, these variations caused the non-uniformity in the arrangement of tiles in the roof frame. There is also a lack of routine maintenance to clean the dry clay that gets stuck on the surface of the mould (Figure 4.17). As a result, the surface of the wet green tiles was become unsmoothed.

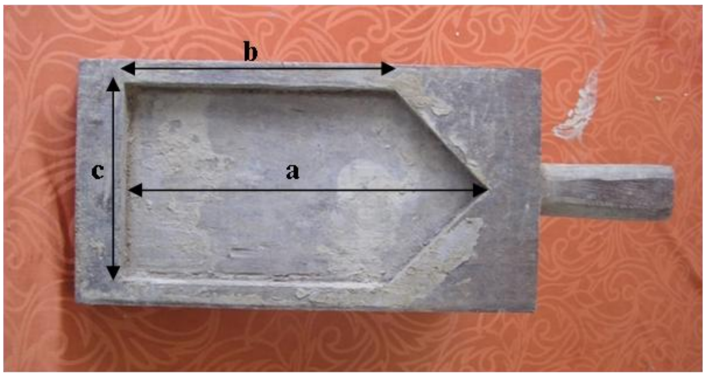

Figure 4.17: The mould
Source: Field study (2013)

(b) Bow-wire

Other than the mould, the wire of the bow-wire cutter that used to trim the excess clay on the surface of mould is rusty and no longer taut (Figure 4.18a). It did not cut well and created uneven-surfaced products. This occurs because the clay that stuck to the wire of the bow is cleaned by rubbing it to the corner of the beam (Figure 4.18b) in the factory.

Figure 4.18: The bow-wire (a) and the beam (b)
Source: Field study (2013)

(c) Kiln

The type of kiln used to fire the tiles is a roofless updraught intermittent Scotch kiln, but no door was built in the wall. The kiln was built of bricks with a thin coat of mud as a binder. This kiln has permanent walls and there are two fire holes in the left side of the walls. The heat from the fire holes is connected to the chamber through thirty numbers of small holes (Figure 4.20) below the left wall. This small holes act as channel for the heat to distribute in the chamber. These holes were constructed using brick that are arranged horizontally.

More than half of the brick at the base area of chamber was arranged alternately horizontal with a space between them to allow the ingress of heat (Figure 4.19). However, the bricks at left area of base were closely arranged. Therefore, the heat that distribute in the chamber was non-uniform where the right area received greater heat compared to the left. Figure 4.20 to 4.24 shows the plan of the kiln.

Figure 4.19: The arrangement of bricks in the base of kiln's chamber
Source: Field study (2013)

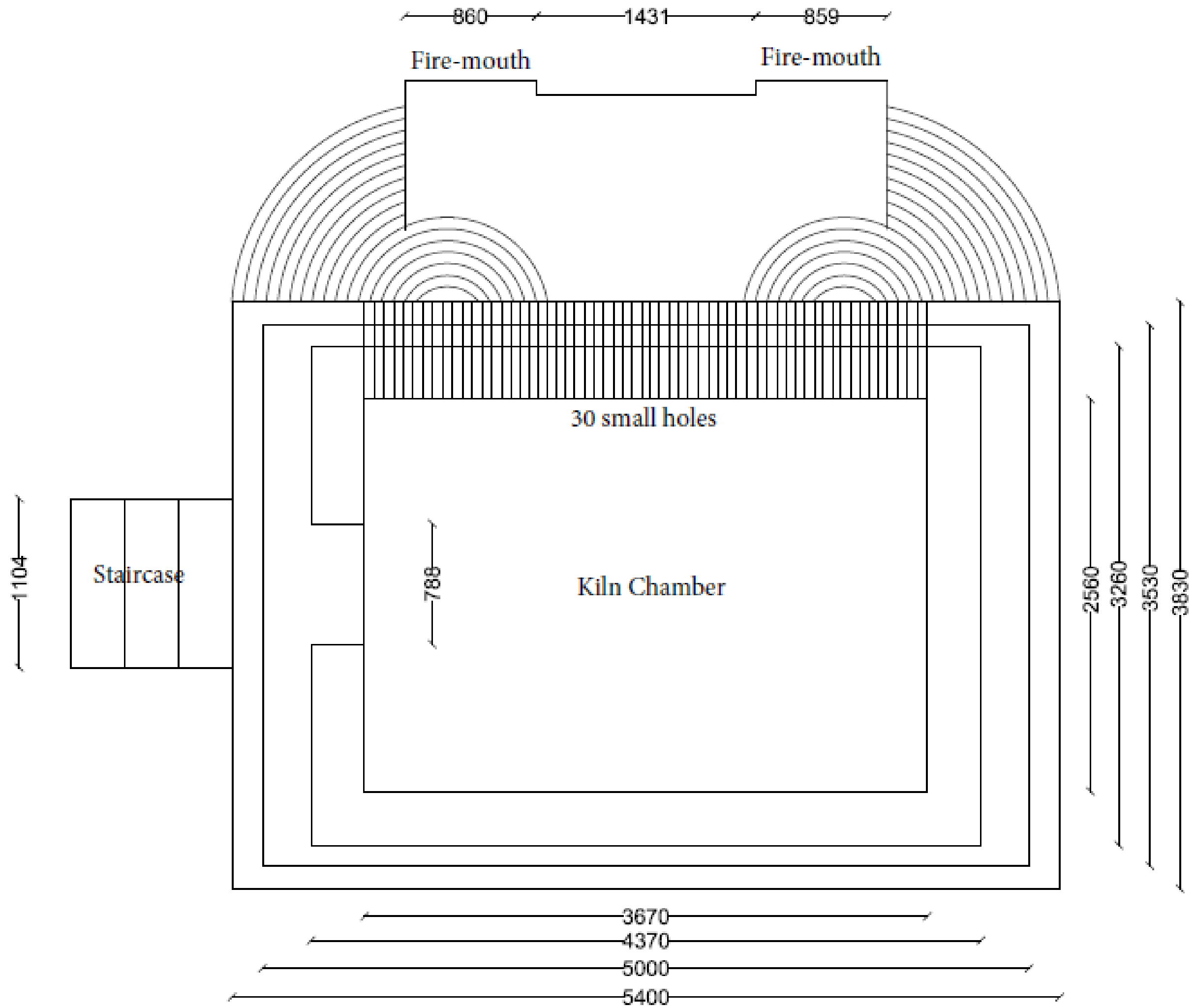

Figure 4.20: The floor plan of traditional kiln
Source: Field study (2013)

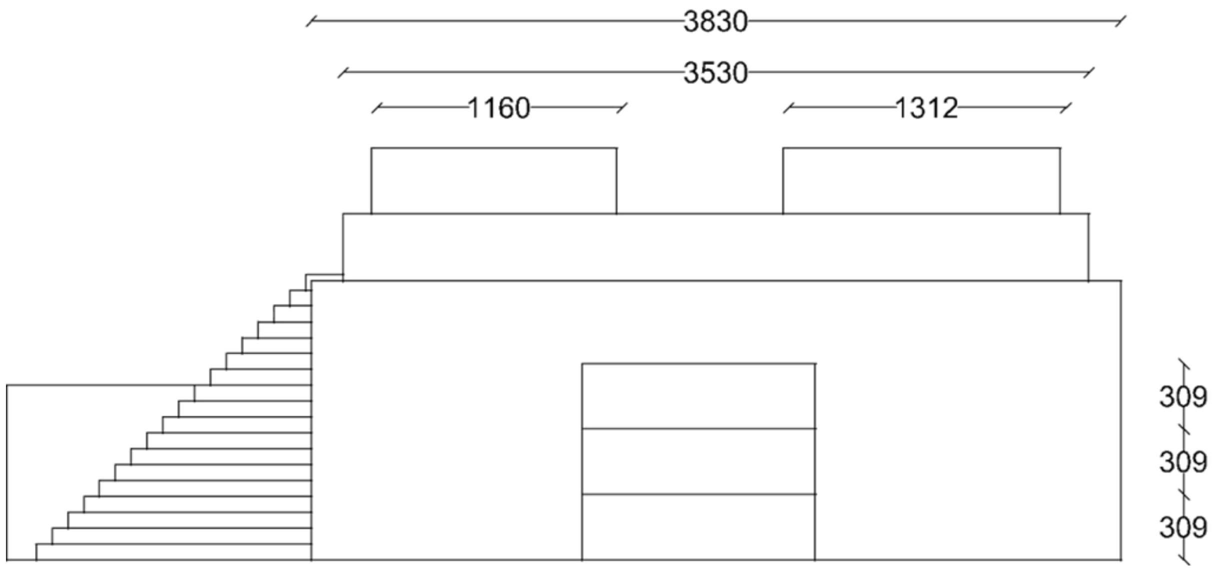

Figure 4.21: The front elevation of traditional kiln
Source: Field study (2013)

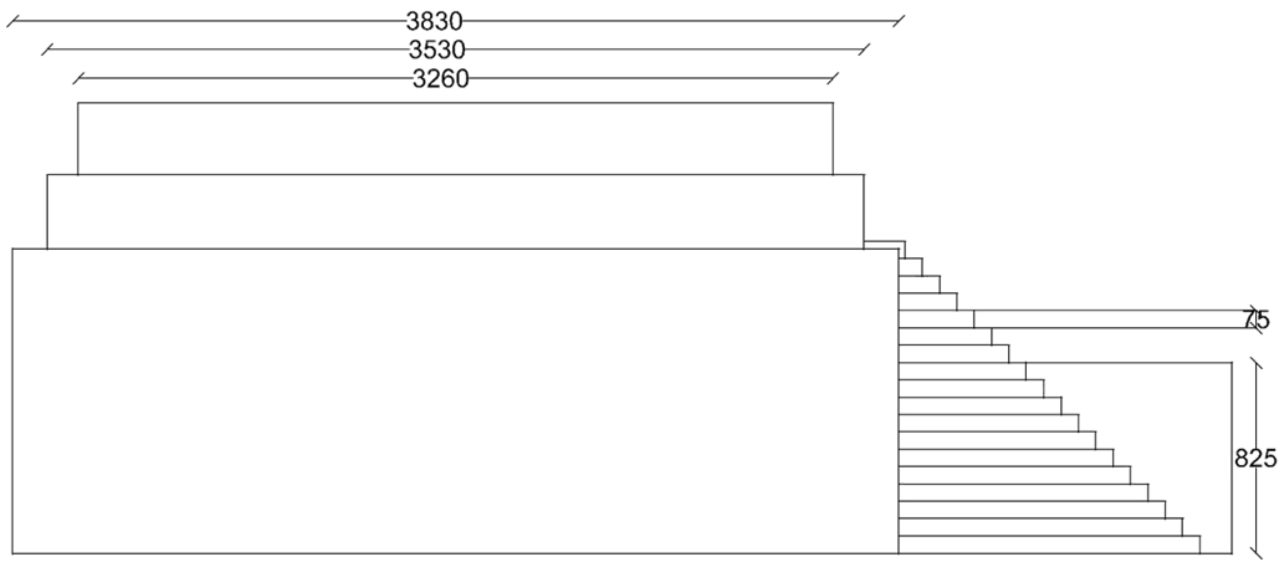

Figure 4.22: The rear elevation of traditional kiln
Source: Field study (2013)

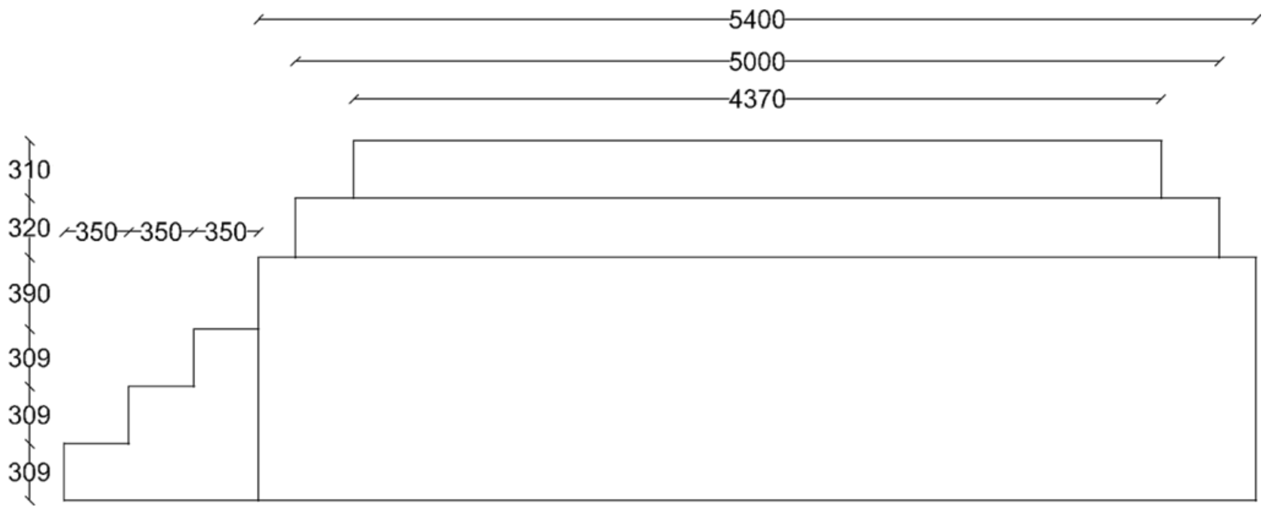

Figure 4.23: Right elevation of traditional kiln
Source: Field study (2013)

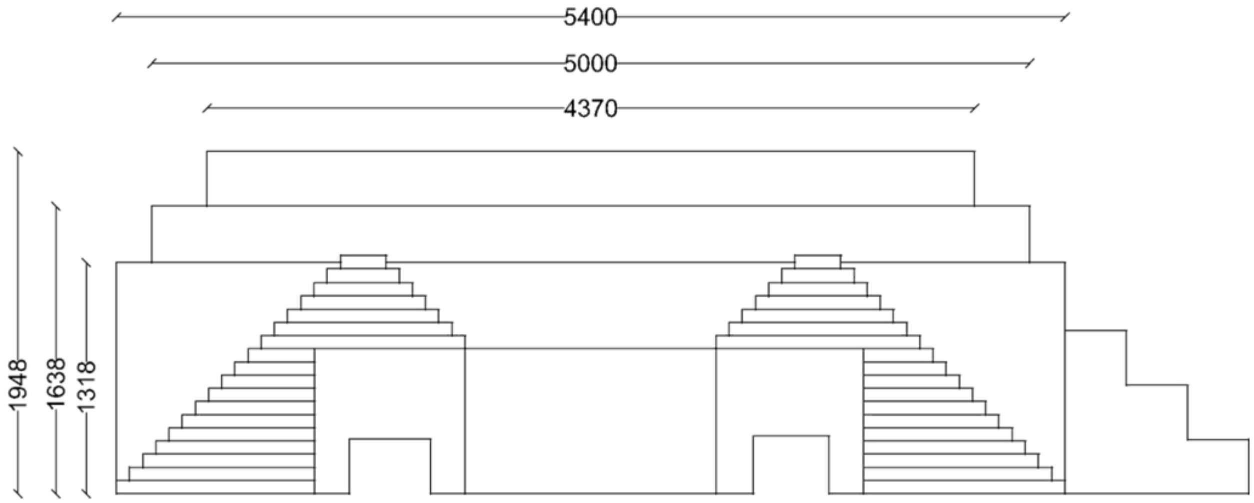

Figure 4.24: Left elevation of traditional kiln
Source: Field study (2013)

4.3 Properties of Singgora Tiles

The properties of Singgora tiles are divided into two sections, firstly the properties of existing Singgora tiles or also known as factory product. Secondly, the properties of Singgora tiles which fired at various temperatures and times.

4.3.1 The properties of factory product

This subchapter presents physical and mechanical properties of existing Singgora tiles which collected at the factory. The physical properties of factory product include surface quality, dimension accuracy, percentage of impurities, grade of sand in the clay and water absorption. On the other hand, the result of flexural strength shows the mechanical property of Singgora tiles.

4.3.1.1 Surface quality

The results are reported as surface quality of green tiles and fired tiles. The total percentage of defect on each sample is estimated based on the percentage of defect on its hook, body and arrowhead.

(a) Green tiles

Table 4.2 presents the surface failure of Singgora tiles. Based on the table, three tiles which constitute 30% of the samples did not satisfy the minimum requirement of BS EN 1411:2006 because the defects on their surface are more than 5%.

The summary of percentage of each type of defect in Table 4.2 is shown in Table 4.3. According to Table 4.3, most of the defect that occurs on the product is rough edge. This defect is also known as an unintentional irregularity along the edge of a tile. The common part of tiles that has rough edge is the hook. Figure 4.25 shows the example of defect that occurred on the surface of green tiles.

Table 4.2: Surface quality of green tiles

Surface fault	Sample of green tiles																													
	G1			G2			G3			G4			G5			G6			G7			G8			G9			G10		
	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a
Crack	√			√						√			√						√						√			√		
Pin hole											√																			
Chip				√											√	√														
Unevenness		√				√		√	√																					
Rough Edge	√		√	√		√			√	√			√			√			√			√	√		√			√		
Visible impurities					√		√							√									√	√						
Estimate total defect on each sample	*8%			*6%			*8%			3%			4%			2%			2%			4%			2%			2%		

Notes: h=hook; b=body; a=arrowhead *Did not satisfy BS EN 14411:2006 requirement

Table 4.3: Summary percentage of defect based on Table 4.2

Surface fault	Green Tiles			
	Hook	Body	Arrow	Total % of defect
Crack	70%	0%	0%	70%
Pin hole	0%	10%	0%	10%
Chip	20%	0%	10%	30%
Unevenness	0%	10%	20%	30%
Rough Edge	90%	10%	30%	130%
Visible impurities	0%	30%	10%	40%

Notes: Each tick (✓) in Table 4.2 constitute 10% of defect

Figure 4.25: Rough edge and unevenness surface of green tile
Source: Field study (2013)

It is observed that 70% of the samples have crack in the hook area. This crack is not running throughout the entire thickness of the product. In addition, 40% of the samples have visible impurities like stone and bark on their surface. An unevenness and chip are found on the 30% of the sample's surface. Only 10% of the samples have the defect of pin hole which visible on their surface.

According to ASTM C1167-03, the good quality of tiles shall be free from defects, deficiencies or bloating, because it would interfere the proper laying of tiles. EN 14411:2006 described that 95% of the ceramic tile surface shall be free from visible defects. Therefore, the green tiles that have greater than 5% of defect shall be rejected in order to ensure the good quality production.

The quality control during making the product is crucial to ensure the quality of finished product. Schunk (2003) notes that the quality control during manufacturing and monitoring by the manufacturer means that only good quality clays used for production chain. Therefore, the quality control, ranging from raw materials to final product is vital to ensure the good quality of Singgora tiles. The defects on the surface of green tiles are occurred because of the defective manufacturing process. The rough along the edge of tile is contributed by the method adopted to shape the clay. For example, the act of holding the end part of wet green tile to form the hook during drying has leaved the finger marks on the tiles as shown in Figure 4.26.

Figure 4.26: The mark of finger along the edge of hook
Source: Field study (2013)

In addition, the rough edge of tile is also contributed by the fault of mould used to shape the tile. As mentioned earlier, there is a lack of maintenance of the mould. Therefore, the dried clay that stuck on the corner of mould (Figure 4.27) has formed the defect on green tiles' surface. The figure also shows the corner and base of mould has not absolutely joint. As a result, the clay which compacted into the mould is not perfectly shaped in the edge area.

According to Figure 4.28, the edge of arrowhead and hook area is not well formed due to the fault of mould. In addition, the practice of shaping the tiles by foot in standing position resulting less directing of clay into the edge and corners of mould. Therefore, the variation in the quality of these handmade goods is inevitable.

Figure 4.27: The dried clay and less joint between the corner and base of mould
Source: Field study (2013)

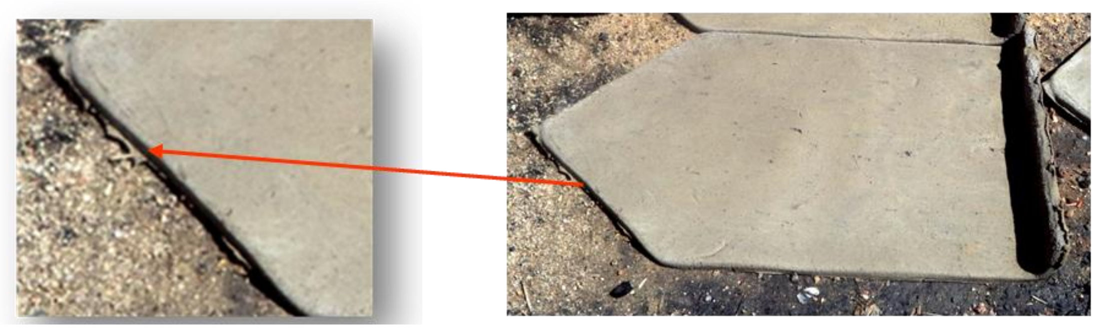

Figure 4.28: The edge area of green tiles is not absolutely shaped
Source: Field study (2013)

The unintentional depression in the body of a green tile is occurred because the impurities on the surface of green tile are removed carelessly. Finger was impressed on a soft surface of wet green tiles to seal the hole that formed after the impurities are removed. Therefore, a mark or pattern appears on it. As a results, the pressed area became notched thus impair the appearance of major area of tiles. Figure 4.29 shows the tiles that have the effect of depression on the surface.

Figure 4.29: Unevenness on the surface of green tiles
Source: Field study (2013)

The uneven shaped of green tile is contributed by the drying area. As previously discuss, the place used to dry the green tiles is an area with uneven soil surface which covered with patches of grass, gravel and sand. The texture of relatively thin and wet green tiles has change according to the texture of drying area as shown in Figure 4.30.

Figure 4.30: Uneven shaped of green tiles due to the improper drying area
Source: Field study (2013)

In addition, the poor drying area also contributes to the defect of visible impurities. The patches of grass, gravel and sand in the drying area has attached to the surface of green tiles. Figure 4.31 shows the tile that has poor appearance due to the visible impurities.

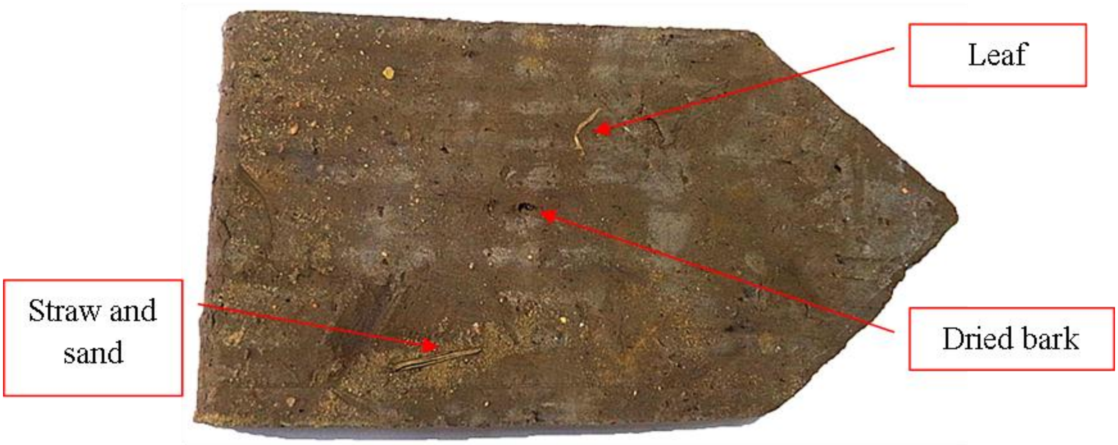

Figure 4.31: The visible impurities in the surface of green tiles
Source: Field study (2013)

The unevenness surface is also appeared on the green tiles when it is knocked with wooden paddle as to flatten them. This act not only caused the green tiles to chip and distort, but also effects the appearance of Singgora tiles.

The most common defect at the hook area is a crack as shown in Figure 4.32. This defect is contributed by the inappropriate method to form the hook during drying process. When the end part of the green tiles is bent upright, the bonding between the particles of plastic clay is disturbed and broken. Therefore, the crack is formed at the bend area.

Figure 4.32: The crack in the hook area of green tiles
Source: Field study (2013)

(b) Fired samples

Table 4.4 presents the type of defect that occurred on the Singgora tiles which fired with traditional kiln at the factory. Based on the table, two of the samples have more than 5% defects on its surface. Therefore, 20% of the samples did not satisfy the minimum requirement of BS EN 1411:2006.

The summary of percentage of each type of defect in Table 4.4 is shown in Table 4.5. According to Table 4.5, the most common defect that occurs on the surface of Singgora tiles is rough edge. This defect will caused the uneven arrangement of Singgora tiles at the roof frame. In addition, the defect of crack is found in 70% of the samples. Four of the samples have visible impurities on their surface while 3 samples have unevenness surface. Only 10% of the samples have the defect of pin hole and chip.

The inappropriate manufacturing process also caused the tiles to have a crack in the back area of hook. These cracks may cause the hook to break and split from their body. As a result, the body of tiles body will slip downwards and leave a gap as mentioned by Abdul and Wan (2002). The gap will allow the penetration of water into the house and lead to the deterioration of building structures especially timber.

Table 4.4: Surface quality of fired tiles

Surface fault	Sample of fired tile																													
	F1			F2			F3			F4			F5			F6			F7			F8			F9			F10		
	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a	h	b	a
Crack	√									√			√			√						√			√			√		
Pin hole														√																
Chip																				√										
Unevenness									√								√									√				
Rough Edge	√		√	√		√	√					√	√			√			√			√	√		√					
Visible impurities					√		√							√									√							
Estimate total defect on each sample	4%			*6%			*6%			3%			4%			2%			2%			4%			2%			2%		

Notes: h=hook; b=body; a=arrowhead *Did not satisfy BS EN 14411:2006 requirement

Table 4.5: Summary percentage of defect based on Table 4.4

Surface fault	Fired Tiles			
	Hook	Body	Arrow	Total % of defect
Crack	70%	0%	0%	70%
Pin hole	0%	10%	0%	10%
Chip	0%	10%	0%	10%
Unevenness	0%	20%	100%	30%
Rough Edge	80%	10%	30%	120%
Visible impurities	10%	30%	0%	40%

Notes: Each tick (✓) in Table 4.4 constitute 10% of defect

The samples that have visible impurities have impaired the major appearance of the tiles. This type of defect is formed due to the un-burnt impurities in the clay during firing. Figure 4.33 shows the bark (a) and stone (b) which incompletely burnt and visible in the surface of fired tiles. The figure also shows a few cracks have formed around the un-burnt impurities.

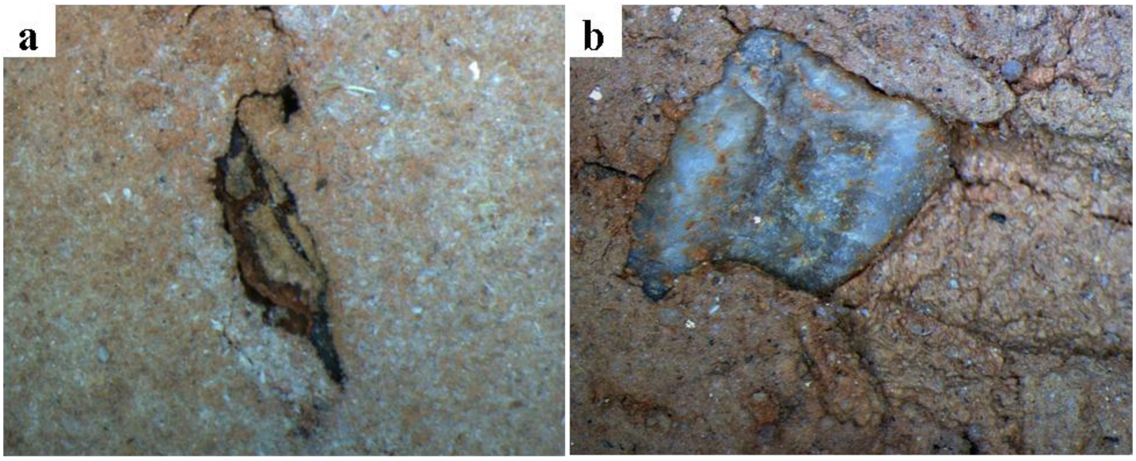

Figure 4.33: The unburnt bark (a) and stone (b)
Source: Field study (2013)

The result from observation discovers that the presence of impurities in the tiles was contributed by the method adopted in the selection and extraction of the raw material. Figure 4.34 shows the common soil profile of soil cutting. The organic material and humus horizon are deposited at the horizon O_1, O_2 and A_1. Shamsuddin (1990) notes that plants like pine and overgrown foliage can live in Bris soil and they will turn to mor humus when decay. These materials are normally removed by sieving the soil during the preparation process (Thompson & Troeh, 1978).

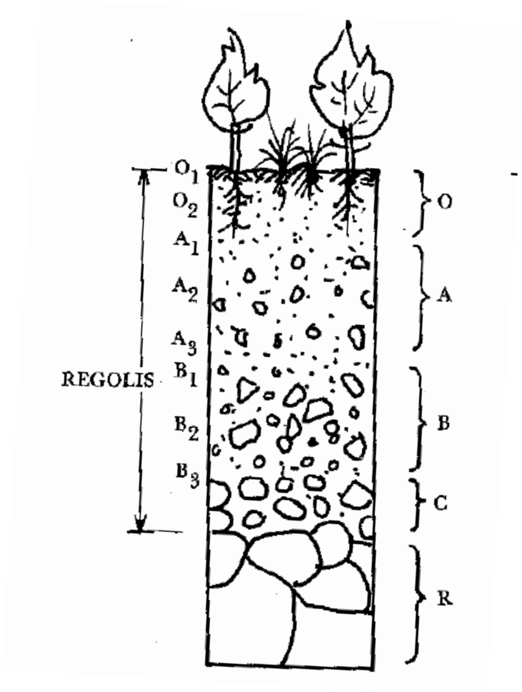

Figure 4.34: The soil profile
Source: Shamshuddin (1981)

In the production of Singgora tiles, the clay is excavated randomly from the surface of paddy field. Therefore, numerous identifiable impurities such as rotten woods, course sands, straws, stones and dry leaves that incorporated at the surface of paddy field are mixed with the clay. It is also not treated before being used to make Singgora tiles. As a result, the impurities that mixed with the clay have reduced the surface quality of tiles.

The pin hole is formed on the surface of product when the impurities had completely burnt as shown in Figure 4.35a. This type of defect not only blemished the surface of tiles, but also increased the water absorption and decreased the mechanical strength of Singgora tiles.

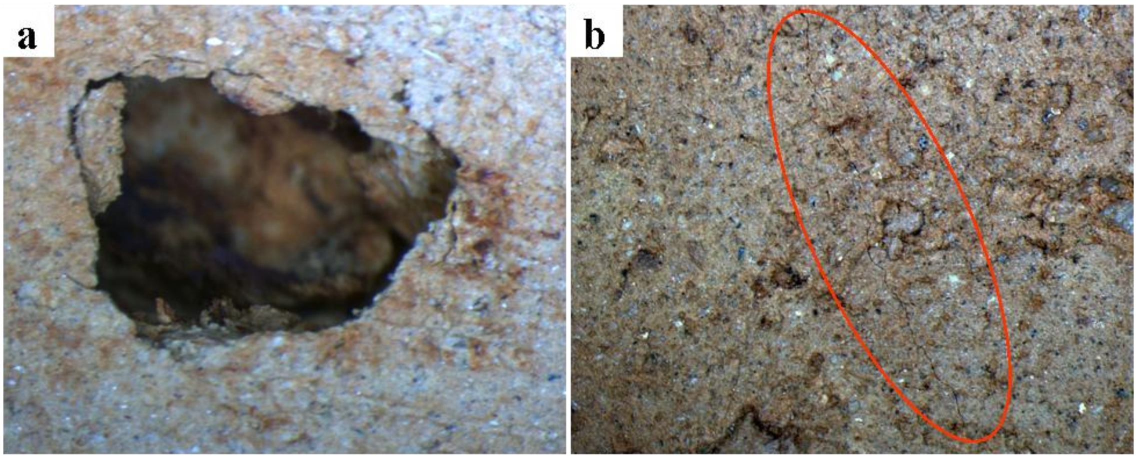

Figure 4.35: The pore (a) and crazing in the surface of tiles (b)
Source: Field study (2013)

Besides that, the hairline crack is also identified at the surface of Singgora tiles (Figure 4.35b). This crack formed when the relatively fragile green tiles are knocked with wooden paddle to flatten their surface.

The uneven surface of Singgora tiles is contributed by the act of removing the impurities on the surface of green tile. In addition, this defect is also occurred when the pallet which stacked with green tiles is poorly stored and exposed to damage by the livestock. Figure 4.36 shows the mark of animal foot which clearly appeared on the surface of tiles after fired.

Figure 4.36: The cat footprint in the surface of Singgora tiles
Source: Field study (2013)

4.3.1.2 Dimensional accuracy

Table 4.6 shows the average and deviation of length, width and thickness of Singgora tiles. In general, the length, width and thickness of Singgora tiles are 208.02±9.04 mm, 163.48±0.83 mm, 6.85±1.03 mm respectively. The percentage of length deviation from the average value is 4.3 % while the deviation of width and thickness are 0.5% and 15.0 % respectively.

Table 4.6: Results of dimension test

Component	Length	Width	Thickness
Mean, mm ($\bar{X}$) [n=10]	208.02	163.48	6.85
Deviation from $\bar{X}$ (σ), mm	9.04	0.83	1.03
Deviation from $\bar{X}$ (σ), %	4.3*	0.5	15.0*
Acceptable deviation, %	2	2	10

*Did not satisfy BS EN 14411:2006 requirement

According to the BS EN 14411:2006 (Table F.1), the percentage of length and width deviation shall fall within ±2.0 % while the thickness is ±10.0 %. The results show that only the width of Singgora tiles has conformed to the standard requirement. Therefore, the existing factory product has non-standardized size, due to the non-uniformity of their length and thickness, although the width is complying with minimum requirement of standard.

In fact, good tiles should be consistent in the size and only vary within allowable tolerance to avoid the different joint sizes. There are a few factors that lead to the variation in the size of Singgora tiles. Firstly, they are made from various size of mould. According to Table 4.1, the maximum difference between the length and thickness of mould is 18 mm and 3mm respectively. In order to minimize size variation from one tile to another, the manufacturer should produce single precise size of mould. By rectifying the mould, they can avoid the sizing variation and produce better dimensional accuracy of product.

The making process also contributes to the difficulties in controlling the uniformity of product's thickness. The traditional method to shape the tiles is less effective. The mould that used to shape the tiles was placed down over the ground with end raised about 120mm. Then, the clay is thrown into the mould; the worker packs it down with foot and pushed off most of the excess. The clay is shoved with a sliding action in standing position. Therefore, the clay did not exactly fitted into the wide space of mould and the uniformity of thickness is difficult to control.

In addition, the uneven shrinkage during drying and firing also contributed to the variability of dimension among the tiles. During drying process, the tiles are left to dry without any repositioning. As a result, the non-uniform dried surface is formed where the above surface shrink greater than beneath surface. In term of firing, the used of traditional kiln has led to the inconsistency heat distribution where the bottom area of chamber received greater heat compared to the top. The Scotch kiln normally produced a large proportion of under and over fired clay products due to the unevenness of the firing temperature (UNIDO, 1984). It has resulting to the variation in shrinkage, causing the finished size of tiles that fired at the bottom of kiln to be noticeably smaller than those fired at the top.

4.3.1.3 Percentage and types of impurities and grade of sand

Table 4.7 shows the percentage of impurities in five green tiles. The results show that the impurities in one piece of Singgora tiles are 0.9±0.1 %. Figure 4.37 shows the types of impurities that contain in the green tiles. These impurities are the decay of vegetable matter that formed in humus and organic loam. It is comprised of dried bark, coal, paddy leaf, straw and small stone. The presence of impurities in clay has contributed to the low quality of raw material.

Table 4.7: Percentage of impurities in each sample

Sample	Weight of green tiles, g	Weight of impurities, g	Percentage of impurities, %
A	439.61	4.60	1.0
B	419.84	3.51	0.8
C	419.28	3.97	0.9
D	430.80	3.47	0.8
E	439.19	3.46	0.8

Figure 4.37: Types of impurities in five pieces of green tiles
Source: Field study (2013)

According to West and UNIDO (1969), the foreign materials including large stone, timber and large root shall be removed to avoid the goods misshapen. The clay should go through the drying, crushing and sieving process before being mixed with water as practice by *Sayong* Potter in Malaysia (Shafiee & Sulaiman 1992). A similar method also practised by potter in Bach Chan, Loas (Shippen, 2005). The quality control during preparing the clay is the key to produce greater and uniform quality of product (West and UNIDO, 1969). It is also contribute to workable clay, improve the strength of dry green tiles and fired products and smoother tiles surface.

Figure 4.38 shows the distribution size of impurities in five samples. Generally, most of the impurities are 1.18 mm and 0.6 mm in size. The results show that 6 % and 16 % of impurities size are 5.00 mm and 2.36 mm respectively. It is comprised of coal, wood, dried bark, straw and other lightweight material. The impurities also consist of high percentage of course sand which is 72 %, in the range of 0.60 mm to 1.18 mm in size. In addition, the percentage of medium and fine sand is 3 % and 1 % respectively.

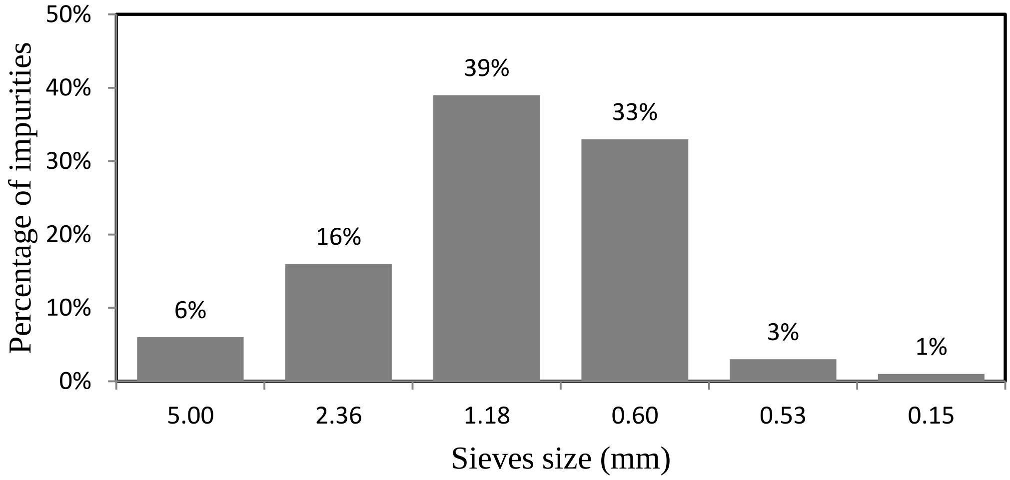

Figure 4.38: Distribution sizes of impurities and sand

The result of this experiment is consistent with the theory by Roslan et al. (2010) where the main mineral in the Bris soil is sand or quartz. The present of high percentage of coarse sand has reduced the strength of Singgora tiles (Stathis et al. ,2004). Toriman et al. (2009) note that 95% of Bris soil is sand and this hinders the plants growth and cause the temperature of the soil to remain high due to lack of plants. Besides, the high percentage of sand also caused the Bris soil to be low inherent soil status, excessive drainage, and poor water holding capacity nutrient as well high both surface temperature and moisture stress (Consulting, 2008).

4.3.1.4 Water absorption

The average water absorption of Singgora tiles is 22 %. Singgora tiles are categorized into Group III, where the water absorption is greater than 10 % (BS EN 14411:2006). Under this category, the Singgora tile is considered to have high water absorption with porous body. When the water absorption is higher, more water is retained in the body of tile which promotes the growth of moss, lichen and small plant.

4.3.1.5 Flexural strength

The flexural strength of existing Singgora tiles is 4.90 N/mm^2 with ±1.26 N/mm^2 standard deviation. It is worth mentioning that the strength of Singgora tiles is less than the minimum typical strength of roof tile, 8.00 N/mm^2, as described by ASM (Kuhn et al., 2000) and BS EN 14411:2006. The low strength of Singgora tiles has hindered its usability for the purpose for which it was designed and manufactured. As mentioned before, there are many factors that contributed to the low strength of Singgora tile. Generally, the low strength of Singgora tiles is develops due to the mistakes during production. The untreated raw material, lack of control during making, poor drying technique and ineffective firing method has contributed to the poorly manufactured product.

The present of 0.9±0.1 % impurities in each piece of Singgora tiles has contributed to the low strength of product with high standard deviation among them. The defects of black heart and pin hole is observed along the fractured end of Singgora tiles after the flexural strength was conducted as shown in Figure 4.39. Black heart is generally owing to the reduction of iron minerals during the firing process (ASTM C1167-03). On the other hand, the pin hole formed when the impurity is burned out. The organic combustible materials such as dried bark, paddy leaf and straw are combustible during firing thus leaving a pore inside the tiles body. The pore has reduced the strength of ceramic.

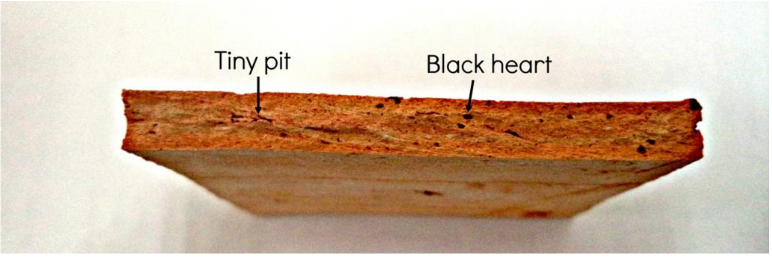

Figure 4.39: Fractured end of Singgora tile
Source: Field study (2013)

The high percentage of standard variation is also contributed by the firing process. During firing, the temperature gradient exists from top to bottom of traditional kiln. As a result, the tiles at the bottom being over-fired compared to the upper tiles. Therefore, the quality of the kiln output is variable.

4.3.2 The properties of Singgora tiles fired at various temperature and time

Based on the properties of factory product, there are a few types of defect that occur on the Singgora tiles. These are including the low surface quality especially rough edge and crack, the un-uniform dimension, high water absorption and easily broken due to low flexural strength. The critical defect facing by Singgora tiles is low strength as the main criteria in selecting the building material is the strength of property as stated by Abdul and Wan (2002). Improving the strength will indirectly reducing the water absorption of Singgora tiles. No improvement is done on the quality of surface of Singgora tiles as to retain the authenticity of this traditional tile through its handmade appearance.

The priority for quality improvement is the strength, which only can be determined by having experiment. Therefore, this second experiment was conducted to find out the effect of firing temperature and firing time on the properties of Singgora tiles. The optimum strength is considered to be achieved when the samples have the strength up to the minimum accepted strength for typical clay roof tile. Based on the result of experiment, the optimum firing conditions is proposed based on the optimum strength achieved by Singgora tiles.

This subchapter presents the result of water absorption test and flexural strength test of Singgora tiles which fired with electric furnace at various temperature and time.

4.3.2.1 Water absorption

Figure 4.40 and 4.41 shows the water absorption of tiles which fired at various temperature and time respectively. A significant linear relationship occurred between water absorption and firing temperature as shown in Figure 4.40.

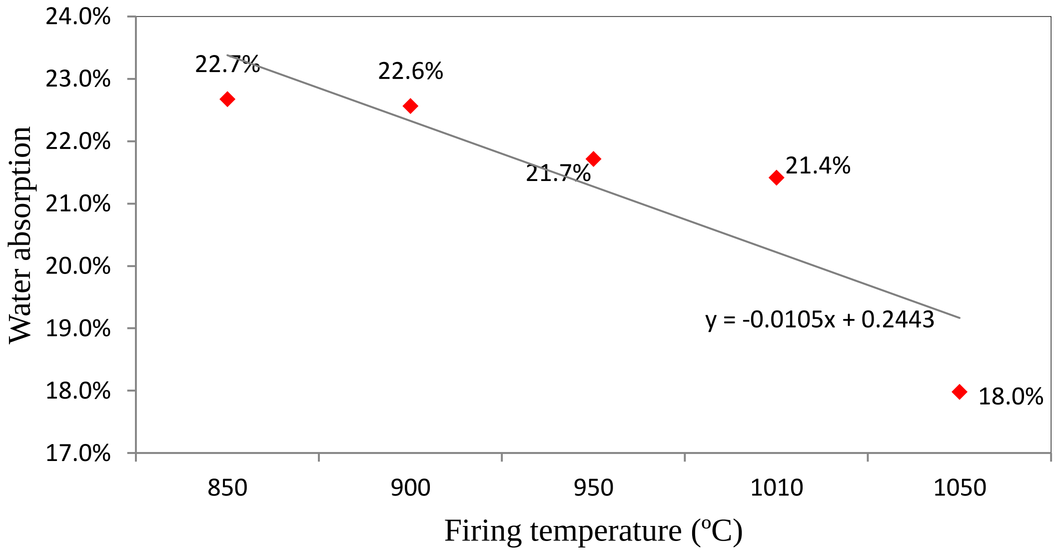

Figure 4.40: Water absorption against the firing temperature (fired for 4 hours)

The result shows that the water absorption is decreased with increased of firing temperature. Sample that fired at temperature 850 °C exhibit a high percentage of water absorption at the beginning of heating ramp. The water absorption development is slightly decreased to 22.6 % with the increase of firing temperature. The water absorption of sample that fired at temperature 950 °C is decreased to 21.7 %, which lower than the water absorption of factory product. As the firing temperature increased, the water absorption of sample that fired at temperature 1010 ºC is decreased to 21.4%. Tiles porosity value is decreased significantly from 21.4% to 18.0% with 15.9% reduction. It is worth mentioning that the value of water absorption for samples fired at temperature 1050ºC is lower than the result obtained by Shamsu (2013).

Figure 4.41 presents the time-dependence curves for water absorption. The effect of firing time on water absorption is insignificant. This finding is similar with other study (Karaman, Ersahin & Gunal, 2006). There is a variation of water absorption when the samples are fired at various firing times.

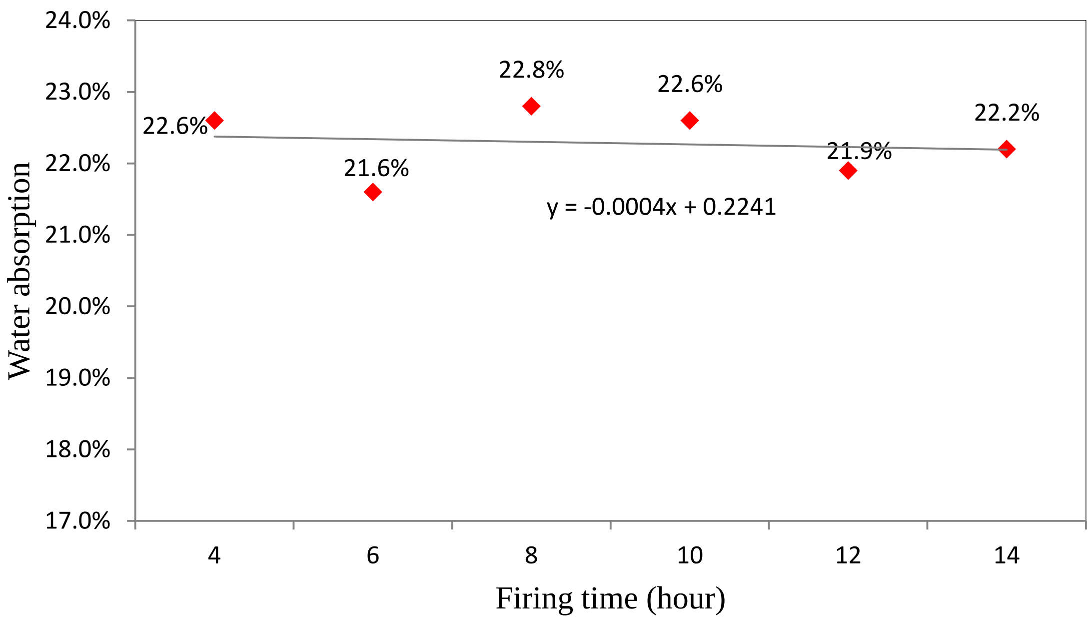

Figure 4.41: Water absorption against firing time (at 900 ºC temperatures)

The lower percentage of water absorption is possessed by sample fired for 6 hours, which is 21.6%. This result shows the reduction of water absorption compared to sample that fired for 4 hour at temperature 900ºC. The sample that fired for 8 hours shows the increment of water absorption by 5.6% compared to sample at 6 hours firing time. A small reduction of less than 1.0% of water absorption is observed on further heating. It is later decreased to 21.9% when the tiles are fired for 12 hours. Finally, the water absorption is slightly increased to 22.2% at 14 hours firing time.

Bernasconi et al. (2011) described a firing duration is the key parameter to promote the vitrification. He further states that the increase in firing time will lead to the decrease of water absorption. According to Figure 4.41, the effect of firing time on water absorption is insignificant. However, in general, the water absorption values obtained at 14 hour of firing is slightly lower than those obtained at 8 hours of firing.

According to EN 14411:2006 (Table F.1), the average water absorption determined by submersion in water for 4 hours must be less than 10%. In this study, water absorption of Singgora tiles produced at each firing temperature and firing time did not satisfy the minimum requirement specified by the standard. High percentage of water absorption obtained in this study indicates that the Singgora tiles are highly porous. There are a few factors that contribute to the high water absorption of clay product. Dan et al. (2009) noted that the pore dimension and distribution is influenced by the quality of raw clay, the amount of water, the presence of additives or impurities in the raw clay and the firing temperature.

The present of high percentage of coarse sand in the clay that used to make Singgora tiles has increased the value of water absorption. This is supported by Bernasconi et al. (2011), where the smaller value of water absorption typically given by the finer size of the quartz grains.

Since the clay that used to prepare the sample was untreated, the presence of organic impurities in the clay has given an effect to the value of water absorption. The burned impurities during firing have left the pore inside the body of tiles and this pore will trap the water thus increased the percentage of water absorption (Dan et al., 2009). However, the samples that fired at high temperature, which is 1050 ºC show lower porosity value because their microstructure contains minimum pores. The formation of the amorphous (non-crystalline) phase at high firing temperatures will decrease the water absorption (Karaman et al., 2006).

In the firing of clay product, the clay body decomposes under the effect of heat. According to Warren (1999), at temperature upwards of 1000ºC, the material becomes semi-molten due to the presence of calcium oxide. He further mentions that at this point, the metakaolin is partially collapse and mass contacts. When a material is allowed to cool slowly, the non-crystalline vitrified materials will accommodate the internal stress through the slow readjustment of glasses (Warren, 1999). During vitrify; the pores begin to fill with glass (Cuff, 1996). Therefore, the remaining pore formed by the combustible organic matter is sealed in by the vitrification of crystalline structure of tile body at elevated temperature. However, the non-combustible material such as stone will remain in the body of Singgora tiles.

4.3.2.2 Flexural strength

This subchapter discuss about the flexural strength of Singgora tiles under the influenced of firing temperature and firing time.

(a) Effect of firing temperature on the strength of Singgora tiles

Figure 4.42 shows the flexural strength and standard deviation of Singgora tiles that fired at temperature between 850ºC and 1050 ºC for 4 hours. The strength of Singgora tiles fired at temperature 850ºC is 4.76 N/mm^2, 900ºC is 4.86 N/mm^2, 950ºC is 5.43 N/mm^2, 1010ºC is 6.03 N/mm^2 and 1050ºC is 8.28 N/mm^2.

The result shows that the strength is increased with the increased of temperature. As mentioned previously, the strength of existing Singgora tiles is 4.90 N/mm^2, which is almost the same flexural strength of 4.86 N/mm^2 at 900ºC. This shows that the temperature in the kiln that used to fire Singgora tiles at the factory is not more than 950ºC. This is consistent with the study conducted by Mason and Hill (1999), where the range of maximum temperature achieved by the traditional kiln is 950±50ºC.

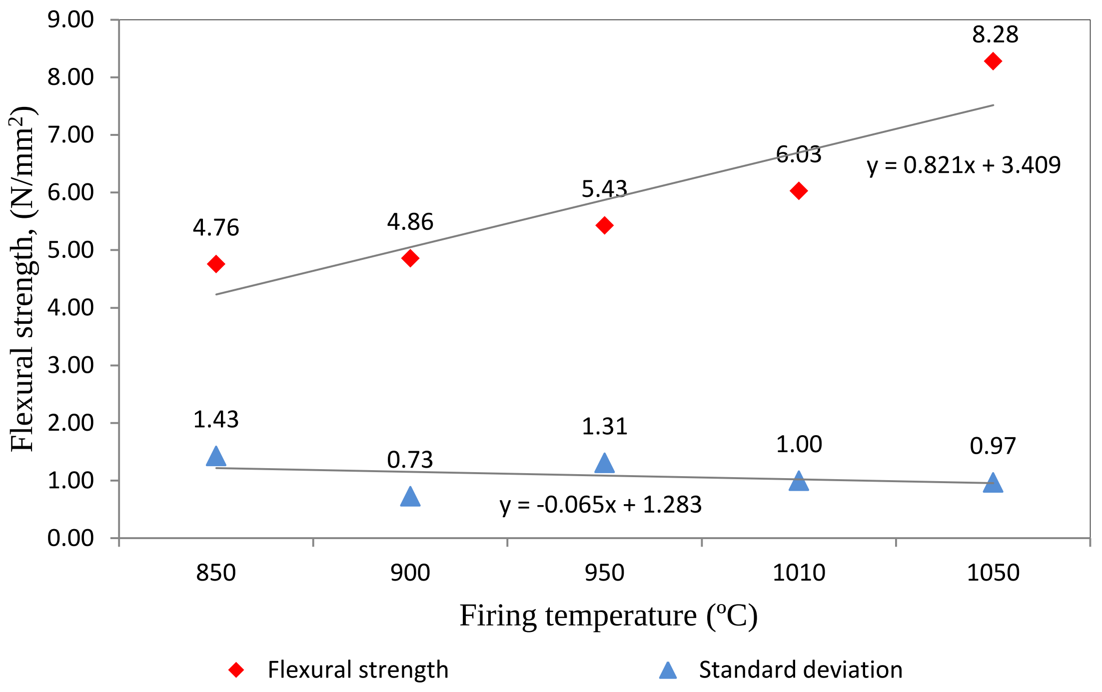

Figure 4.42: Flexural strength against the firing temperature (fired for 4 hours)

According to Figure 4.42, the change of strength for the samples fired at temperature between 850ºC and 900ºC is insignificant with only 2.1% of increment. However, the strength of 4.86 N/mm^2 is increased by 11.7% at temperature 950ºC. This percentage of increment is almost stay on the same level of strength at temperature 1010ºC and then rapidly increased on further heating. The significance change of flexural strength is observed when the samples are fired at the temperature 1010ºC to 1050ºC. The increment of 37.3% is observed at temperature 1050 ºC.

Overall, the increment of strength at firing temperature from 850ºC to 1050ºC is 73.9%. In general, the lower water absorption will contribute to the durability and strength of tiles. According to Figure 4.40, the lowest water absorption is attained by the samples fired at highest temperature, 1050ºC. The results of flexural strength are consistent with the percentage of water absorption of samples at each firing temperature.

Cuff (1996) notes that if the product is over-fired, too much glass will form in the body and the ceramic will become brittle and easily break. According to Figure 4.42, there is no drop of strength at the maximum firing temperature, 1050 °C. Therefore, the maximum strength of Singgora tiles may be increased beyond 8.28 N/mm^2 if the firing temperature is further increases. However, if further heating shows the decrease of flexural strength, 1050 °C is the optimum firing temperature for Singgora tiles.

According to Ece & Nakagawa, (2002), the reliability of the test method depends on the collection of the best representative samples. The standard deviations explained the reliability of result. A low deviation indicates that the data points to be very close to the mean and more reliable while high standard deviation shows the data points are spread out over a large range of values and less reliable.

According to Figure 4.42, the standard deviation at each maximum firing temperature is decreased when the firing temperature increased, except for sample that fired at temperature 900 ºC. The drop of standard deviation at this point is likely due to the less presence of impurities inside the sample compared to the other samples. The increment of strength and reduction in standard deviation for the samples at 1050ºC firing temperature is closely related to the burning of organic matter at temperature above 900ºC (Fraser, 2000).

Overall, the reliability of Singgora tiles can be increased if the product is fired at high temperature although the low quality of raw material (untreated clay) is used as raw material. The effect of impurities to the mechanical properties of Singgora tiles is minimized by increasing the firing temperature. It is suggested that the Singgora tiles are fired at temperature 1050ºC for 4 hours as to achieve the minimum strength of clay tile as described by ASM (Kuhn et al., 2000).

(b) Effect of firing time on the strength of Singgora tiles

The change of flexural strength of Singgora tiles with the increase of firing times is given in Figure 4.43. The samples are fired for 6 to 14 hours at temperature 900 ºC. The data points represent the strength of Singgora tiles fired for 6 hours is 8.29 N/mm^2, 8 hours is 8.58 N/mm^2, 10 hours is 9.07 N/mm^2, 12 hours is 9.39 N/mm^2 and 14 hours is 9.33 N/mm^2.

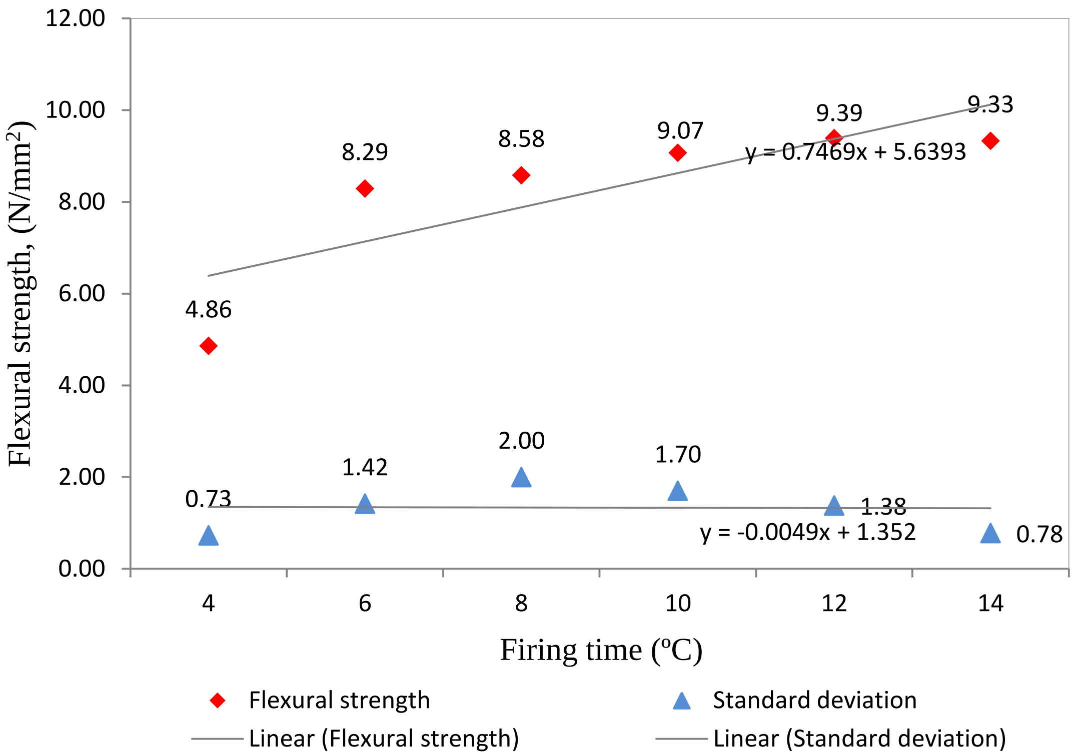

Figure 4.43: Flexural strength against the firing time (at 900ºC temperature)

The results show the flexural strength increased with increasing firing time and reached maximum value of 9.39 N/mm^2 at 12 hours firing time. Surprisingly, all the data is up to the minimum value of typical strength of clay tile except sample fired at 4 hours.

The lowest flexural strength is observed at time 4 hours. Next, the strength of tiles fired for 6 hours is increased to 8.29 N/mm^2, which almost twice the flexural strength of factory product. An insignificance change of strength is observed when the firing time gradually increased from 6 to 8 hours. The flexural strength is increased by 3.5% with increasing firing time at this point. The increment has become pronounced as the firing time is further increased to 10 hours. Strength 8.58 N/mm^2 those achieved at 8 hours is increased by 5.7% when the time is extended to 10 hours. The highest flexural strength is observed at time 12 hours. Samples that fired for 12 hours tend to have 3.5% greater bending strength than those fired at 10 hours. The strength of Singgora tiles which fired for 12 hours is 9.39N/mm^2, which almost double the strength obtained by Shamsu (2013). The flexural strength value is decreased on further heating. A insignificance change of strength is observed when the firing time increased from 12 to 14 hours. Overall, the increment of strength of Singgora tiles at firing time 4 to 14 hours is almost twice.

According to Figure 4.43, the standard deviation of sample is decreased with the increased of firing time, except for sample fired for 4 and 6 hours which dropped at that point with unknown reason. It is probably caused by less presence of impurities in the samples.

This experiment has proven that the effect of impurities to the mechanical properties of Singgora tiles can be minimized by increasing the firing times. The reliability of Singgora tiles is increased when the product is fired for longer duration although the untreated clay is used as raw material. As to achieve the minimum typical strength of clay tile, the most economic ways in firing the Singgora tiles is at temperature 900ºC for 6 hours.

4.4 Summary

The results of observation show that the defects of Singgora tiles are contributed by the method of preparing of the clay, forming the tiles and the drying process as well as the firing process. Table 4.8 shows the summary of the finding for case study which is the observation on the manufacturing process of Singgora tiles.

Table 4.8: Summary of finding for case study

Manufacturing Process and Equipment	Inappropriate method	Remarks
Clay winning and preparation	No selection of clay during digging	Impurities are also taken
	Clay is not treated to remove the impurities	Contribute to unsmooth surface and low strength of Singgora tiles
Forming the tiles	Method used to compact the clay into the mould is less effective	Contribute to the rough edge defect
	Wet clay tiles are stacked on the pallet	Caused the wet tiles to easily deform
	The pallet is poorly stored and resting on the ground and exposed to livestock	Contribute to uneven surface defect
Drying the tiles	Place used to dry the green tiles is an area with uneven ground surface covered with grass, gravel and sand	Impurities has stuck to base of green tiles
	The drying area is accessible to livestock and children which sometimes trample on the tiles	Contribute to uneven surface defect
	The green tiles is not reposition during drying	Caused the green tiles to be warped, cracked and chipping due uneven drying
	The green tiles are stacked onto a barrow and transferred to the factory	Many green tiles broke due to the stack
	Before stored, the uneven green tile is knocking with paddle to flatten the surface	Contribute to defect of crack

Manufacturing Process and Equipment (Cont'd)	Inappropriate method	Remarks
Drying the tiles (Cont'd)	The green tiles is stacked without the use of rack before loaded into the kiln	The green tiles will reabsorb the moisture and if it is inserted directly to the kiln, may lead to the expansion of open cracks
	The green tiles is stacked without the use of rack before loaded into the kiln	The green tiles will reabsorb the moisture and if it is inserted directly to the kiln, may lead to the expansion of open cracks
Firing the tiles	The worker stepped on the green tiles during loading process	Many green tiles broke due to the imposed load by worker
	Green tiles are closely stacked and broken Singgora tiles are used to fill the gaps between them.	Created uneven heat distribution which yield various strength of product with multi-colour effect
	Approximately forty thousand green tiles are stacked in ten layers in kiln chamber	Many tiles at lower part of chamber are broken due to overloading from upper layer
	The top layer of green tiles is only cover with bricks.	The heat can penetrate through the gaps between the brick. Therefore, large quantities of fuel are used to fire the green tiles.
Equipment	<u>Wooden mould</u> ▪ Non-uniform size ▪ The dried clay that stuck on its surface is not cleaned.	▪ Yield varies size of product ▪ Contribute to unsmooth surface
	<u>Bow-wire</u> ▪ Rusty and no longer taut	▪ Contribute to uneven-surfaced product
	<u>Kiln</u> ▪ The design of kiln's base is ineffective	▪ Yield ▪ Uneven distribution of heat, thus produced varies strength of product.

Overall, the properties of factory product are less than the standard requirement. It is including the surface quality, dimension, water absorption and flexural strength. Table 4.9 shows the summary of experimental results for the green and fired tiles. The variation in quality of existing Singgora tiles in terms of dimension, surface quality and strength is contributes by the manufacturing faults including raw material, tool and equipment as well as human operators.

Table 4.9: Summary of finding for experimental works (Experiment 1)

Properties of factory product			
Test	Min. Accepted Value	Result	Remarks
Surface quality	A minimum of 95% of the tiles shall be free from visible defects	Green tiles Out of 10 samples, 30% of them have more than 5% surface defect.	The most common surface defects that occurred are rough edge and crack.
		Fired Tiles Out of 10 samples, 20% of them have more than 5% surface defect.	
Dimensional accuracy	The acceptable deviation Length: 2% Width: 2% Thickness: 10%	The deviation of length and thickness are more than the minimum accepted value. Only width is within the allowable deviation.	The product is rejected because it's two criteria (length and thickness) not complying with the standard.
Percentage and type of impurities	Clay should not consist an impurities	0.9±0.1% of impurities in each piece of green tiles. The type of impurities present are dried bark, coal, paddy leaf, straw and small stone.	The low quality of clay is used to make Singgora tiles due to the presence of high percentage of impurities.
Grade of sand	Low water absorption is given by clay contains fine sand.	The clay consists of 78% course sand, 3% medium sand and only 1% fine sand.	High percentage of course sand will contribute to high water absorption and reduced the strength of product.
Water absorption	Less than 10%	The water absorption of Singgora tiles is 22%	Singgora tiles have high water absorption with porous body.
Flexural Strength	Minimum typical strength of clay tiles is 8.00 N/mm^2	The strength of Singgora tiles is 4.9 N/mm^2 with ±1.26 N/mm^2 standard deviation.	Singgora tiles are brittle and least reliable product.

Table 4.10 shows the summary of finding for Experiment 2, which is the property of tiles that fired at various conditions. The strength of Singgora tiles is increased and water absorption decreased with the increased of firing temperature from 850 ºC to 1050 ºC. Prolonged firing time had no significant effects on the water absorption of Singgora tiles but contribute to a higher strength of product. The results of experimental works show that the acceptable strength of Singgora tiles is achieved at 6 hours firing time. Therefore, unnecessary longer firing time should be avoided to save time, money and energy. The results obtained in this study are applicable to the properties of tiles produced under similar conditions and raw materials.

Table 4.10: Summary of finding for experimental works (Experiment 2)

Properties of Singgora tiles fired at various temperature and time			
Test	Min. Accepted Value	Result	Remarks
Water absorption	Less than 10%	The water absorption decreased with increased of firing temperature. The effect of firing time on water absorption is non-significant. The water absorption of sample at each firing temperature and firing time is more than 10%.	The water absorption of Singgora tiles can be reduced by firing at higher temperature.
Flexural Strength	8.00N/mm^2	The strength is increased with the increased of temperature and time. Samples that fired at temperature 1050ºC for 4 hours and 900ºC for 6 hours or more have greater strength than 8.00N/mm^2. The standard deviation of sample is decreased with the increased of firing temperature and time.	The optimum firing condition of Singgora tiles is 1050ºC for 4 hours or 900ºC for 6 hours. The effect of impurities can be reduced by firing the Singgora tiles at higher temperature and longer duration.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusion from this research including the main findings and research suggestions. Moreover, the chapter also describes some recommendations for further researches. The research limitation is stated at the end of the chapter.

5.2 Conclusion

This subchapter present the summaries of key finding from the literature review, case study and experimental works. The conclusion is including the factors that affecting the quality of Singgora tiles, properties of factory product, properties of tiles that fired at selected firing conditions and the optimum firing conditions for making Singgora tiles. The following outcomes are obtained from the research:

1) The factors that affecting the quality of Singgora tiles produced by local factory process

Generally, there are three factors that affecting the quality of clay product comprise of raw material, the technique of handling the clay and forming the component and the firing condition.

i) Raw Material

The main elements in clay, which comprised of clay minerals, accessory minerals and impurities has great influence on the properties of the product. The present of appropriate amount of quartz in clay will provide the product strength. However, the use of high amount of coarse grain quartz will reduced the bending strength. Besides, the presence of organic matter leads to low mechanical strength and formation of microstructure cracks. Greater strength can also be achieved by using ideal distribution grain size of the soil.

The presence of fine grain clay and the absence of carbonates in clay will reduce the porosity thus lower the water absorption. Besides, the low water absorption is also given by the clay that contains finer size of quartz. The high porosity of clay product is also related to high percentage of kaolinite in the clay mineral and low percentage of alkaline flux. Other than water absorption and strength, the other important property of clay is the colour of finishes product. This colour is determined by the presence of iron in the clay.

ii) Technique of handling the clay and forming the component

The selection of clay is crucial and any impurities are to be avoided either by selective winning or through selection from the won material. This is important for the performance and durability of clay product. Clay required certain preparatory process before being used to make product. The most common fault which constitute to the low quality of clay is uneven mixing and failure to separate out the impurities from the clay. The balance amount of sand, clay and silts and appropriate amount of water will constitute to the good quality of raw material. Besides, the addition of filler such as grog and sand may improve the strength of clay body. After the clay is shaped to the required shape, it must be handling with care until further drying brings it to handleability. After shaped, the green product will subject to drying process to allow them to shrink, thus prevent twisting and cracking in the kiln. The poor handling during drying will produce misshapen product.

iii) Firing Condition

The final stage of making clay product is firing process. The design and operation of the kiln will determine the efficiency of firing cycle and the quality of output. The greater distribution of heat will produce greater quality of product in term of strength. Other than firing equipment, the firing process itself is an important element to produce great quality of clay product. The action of fire will give hardness, colour and permanent shape to clay product. The high firing temperature and longer firing duration will contribute to the greater quality of strength and reduced the porosity of clay product.

The greater strength of clay product can be achieved when the degree of vitrification is developing without deforming during firing. The vitrification is occurred at high temperature, which ranging from 1000 ºC to 1300ºC. Moreover, firing duration also the key parameter to promote the vitrification, where longer firing time will decrease the water absorption. The low water absorption contributes to the greater mechanical strength as well as slows down the deterioration of product.

From the finding of case study, one of the factors that contribute to the low quality of Singgora tiles is the technique of handling the clay and technique of forming the tiles. A lot of mistakes were observed during making process at the factory. The study found that there is no proper quality control from the beginning until the end of production process. The clay that used to make the tiles is not carefully selected to be used as raw material. The mistake makes during extraction of raw material is the clay excavated from the top surface of paddy field. Therefore, the impurities that deposited at the surface of the soil are also taken. Besides, there is no treatment process is done to remove these impurities that mixed with clay.

The method of shaping also contributes to the defects of the product. To form the shape of Singgora tiles, the clay is compacts into the large surface area of mould by foot in standing position, thus the uniformity of thickness and shape of product are difficult to control. The green tile also poorly stored and exposed to damage by animals. The study also discovered that there is no designated area to dry the green tiles. The place used to dry the green tiles is an area with an uneven ground surface covered by patches of grass, gravel and sand. The practice to bend upright the end part of the tiles to form the hook during drying caused the area of bending being cracked.

A lot of green tiles are broken during the loading process into the kiln due to the imposed load by the worker. Besides, heat is unevenly distributed in the kiln chamber as the kiln was overloaded with forty thousand pieces of tiles. The heat inside the kiln chamber is not effectively trapped because the top layer of green tiles is only covered with closely arrangement of bricks without mortar which the heat still able to penetrate through the gaps. In addition, the defect on the product is also contributed by the equipment that used to make the tiles. The uniformity of mould and the maintenance of bow wire are not given enough emphasis. Besides, the operation of the traditional kiln is ineffective.

2) The physical and mechanical properties of Singgora tiles produced by local factory

The most common defect that found on the surface of green and fired tiles is rough edge. In term of dimension, the length and thickness of the product is varied in size. The uniformity of thickness is difficult to control because it is affected by the tool and method adopted to make the tiles at the factory.

The study also discovered that 0.9±0.1% of impurities presents in each pieces of Singgora tiles. These impurities are formed by the decay of vegetable matter in the clay. Besides, the result of sieve analysis shows the high percentage of coarse sand in the clay. In addition, the Singgora tile is categorized as high water absorption product. The flexural strength test shows the Singgora tiles is brittle product because its strength is less than the typical strength of roof tile. The Singgora tiles are also considered as unreliable product due to the high standard deviation in strength.

3) The physical and mechanical properties of Singgora tiles at selected firing condition

The water absorption of Singgora tiles is decreased with the increased of firing temperature. The effect of firing time on water absorption is insignificant. The presence of impurities in the body of tiles has contributed to the high water absorption of Singgora tiles at each firing condition. The results of flexural strength test show that the strength of Singgora tiles is increased with increasing firing temperature and firing time. The variation of the standard deviation among the sample at each firing temperature is contributed by the presents of impurities inside the fired body. The deviation of strength from the mean value is decreased when the firing temperature and time are increased. Therefore, the reliability of the product is also increased.

4) The optimum firing conditions for making Singgora tiles

The firing temperature and time help to explain the reliability of the Singgora tiles. The reliability of product is decreased when the standard deviation among the strength of tiles is increased. The effect of impurities inside the body of tiles can be reduced if the product is fired at higher temperature and longer firing duration. The typical strength of roof tiles can be achieved by firing the Singgora tiles at temperature 1050ºC for 4 hours or 900ºC for 6 hours. If this firing condition is adapted to make Singgora tiles, the tiles will become less defective due to the increment of strength compared to the existing strength of factory product.

5.3 Research Suggestion

The findings in this study suggest that the vital step to improve the quality of Singgora tiles is the improvement in the manufacturing process. The quality control during manufacturing process is important to produce greater quality of product. The surface quality of Singgora tiles can be improved by providing proper storage and drying area for green tiles. Besides, the mistake of human operator such as finger mark on the bend area and unintended depression on the surface of tiles should be avoided. It is suggested that the uniformity and maintenance of traditional tools is emphasized.

The quality of raw material is important for the quality improvement. The surface of paddy field which consists of impurities must be removed before the clay is extracted. Besides, the clay should be treated to remove the impurities before being used to make tiles. The treated clay can improve both strength and surface quality of Singgora tiles. However, if the strength is only the major concern to be improved, the effect of impurities inside the clay can be minimized by improving the firing process.

The results of the experimental works show that the strength of Singgora tiles is improved by firing at higher temperature or longer duration. Realistically, the maximum firing temperature achieved by traditional kiln is 950±50 ºC. Therefore, the industry can maintain the usage of this firing equipment but alter its operation. They can improve the quality of their product by prolong the existing timing of firing the Singgora tiles. It is suggested that the firing time on site is lengthen to another one day or more. Although the cost of firing process will be increased, the damage or waste product will be decreased. Overall, the production cost is decreased and greater quality of output is produced.

The improvement of firing process not only focuses on the firing time but also the operation of kiln itself. The heat circulation in the kiln can be improved by sealing the gaps between the bricks at the top of the kiln with mud. In addition, loading process of green tiles into the kiln chamber should be handled with sufficient care. It is suggested the door is built in the wall to avoid the worker to step the green tiles during loading process. If the manufacturer affords to change the traditional kiln to electrical kiln, it is suggested the Singgora tiles are fire at temperature 1050ºC for 4 hours.

The outcome of this study may help the small scales industry to improve the quality of their product without substantial increment in the capital cost. In fact, most of the entrepreneur can not modernize their skills, tools and technique of production if there is no financial assistance provided because they do not able to afford it. In addition, they may not trust the new technology or have no way to make appropriate adaption in their products. Therefore, the result of this research may help to improve their industrial by producing greater quality of product and preserving the tradition of product making.

5.4 Recommendation for Further Research

This study identifies a few topics for further research in improving the industry of Singgora tiles. The topics are:

[1] The optimum thickness for Singgora tiles. It is suggested that samples are prepare using treated clay, and the process of shaping and drying the green tiles are under quality control. The samples are fired using traditional kiln at the factory.

[2] The process and tool used in the production of Singgora tiles. For example, design a simple apparatus to treat the clay so that a better quality of raw material will be used to make Singgora tiles. The apparatus is designed at low cost but adapted with the current traditional production.

[3] The traditional kiln. Further investigation on the design of kiln can be carried out to improve its operation. The improvement of design may save the capital cost as well as the running cost by reducing the use of fuel.

5.5 Limitation of the Study

There are a few limitations in this research. Firstly, the method used to fire the samples in laboratory is different from the actual firing at the factory. It includes the size of tiles, type and operation of firing equipment and arrangement of green tiles during firing. In the manufacturing site, the Singgora tiles are fired using traditional kiln at uncontrolled temperature for a several days. Conversely, in laboratory, the apparatus used is electrical furnace where the operation is under control.

Secondly, other factors that affecting the quality of Singgora tiles is unavoidable in this study. The poor quality control in producing the green tile had given the impact to the result of experiment. For example, the presences of organic impurities in the collected green tiles have significantly affected the strength of tested samples. Although the selection of samples is carried by examining the quality of its external surface, the presence of impurities inside the body of green tiles is inevitable.

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LIST OF PUBLICATION AND PAPERS PRESENTED

1. Hidayah, A., Rodiah, Z., & Zuraini, M. A. (2014). Properties of Traditional Clay Roof Tiles Manufacture in Kelantan, Peninsular Malaysia. *Built Environment Journal, 11(2).*
2. Hidayah, A., Rodiah, Z., & Zuraini, M. A. (2013). *Singgora Tiles: Perception of the Community in Kota Bharu, Kelantan.* Paper presented at the The 3rd International Building Control Conference (IBCC) 2013, The Royale Chulan, Kuala Lumpur.
3. Hidayah, A., Rodiah, Z., & Zuraini, M. A. (2013). *Properties of clay plain tiles in Kelantan.* Paper presented at the 7th ASEAN Post Graduate Seminar in Built Environment (APGS) 2013, Faculty of Built Environment, University of Malaya, Kuala Lumpur.

APPENDICES

Appendix A: Result of water absorption

Experiment 1 - Samples collected from local factory

Sample	Original weight (W1), g	Weight after boil (W2), g	Water Absorption
T9	65.85	80.00	21.5%
T10	67.62	82.50	22.0%
T11	69.84	83.42	19.4%
T12	66.78	82.15	23.0%
T13	68.54	85.00	24.0%
		Total	110.0%
		Mean	22.0%

Experiment 2 - Samples fired at temperatures 900 ºc for four hours

Temperature, ºC	Sample	Original weight (W1), g	Weight after boil (W2), g	Water Absorption
850	A9	66.33	81.37	22.7%
	A10	67.21	83.00	23.5%
	A11	70.15	86.54	23.4%
	A12	66.51	80.52	21.1%
	A13	69.52	85.54	23.0%
			Total	113.6%
			Mean	22.7%

Temperature, ºC	Sample	Original weight (W1), g	Weight after boil (W2), g	Water Absorption
900	B9	68.51	83.52	21.9%
	B10	67.24	82.54	22.8%
	B11	66.21	81.15	22.6%
	B12	62.34	76.90	23.4%
	B13	69.45	85.00	22.4%
			Total	113.0%
			Mean	22.6%

Temperature, ºC	Sample	Original weight (W1), g	Weight after boil (W2), g	Water Absorption
950	C9	72.85	90.12	23.7%
	C10	78.65	94.32	19.9%
	C11	79.00	96.70	22.4%
	C12	79.48	96.74	21.7%
	C13	80.15	96.74	20.7%
			Total	108.4%
			Mean	21.7%

Temperature, ºC	Sample	Original weight (W1), g	Weight after boil (W2), g	Water Absorption
1010	D9	65.93	80.05	21.4%
	D10	66.51	82.21	23.6%
	D11	66.00	81.21	23.0%
	D12	69.82	83.24	19.2%
	D13	70.51	84.31	19.6%
			Total	106.9%
			Mean	21.4%

Temperature, ºC	Sample	Original weight (W1), g	Weight after boil (W2), g	Water Absorption
1050	E9	77.46	91.39	18.0%
	E10	76.52	89.43	16.9%
	E11	76.15	90.12	18.3%
	E12	69.14	82.00	18.6%
	E13	68.32	80.9	18.4%
			Total	90.2%
			Mean	18.0%

Experiment 2 - Samples fired at temperatures 900 ºc at various hours

Time, hour	Sample	Original weight (W1), g	Weight after boil (W2), g	Water Absorption
6	F9	82.54	99.65	20.7%
	F10	81.65	99.26	21.6%
	F11	79.89	97.64	22.2%
	F12	82.75	99.80	20.6%
	F13	75.65	93.00	22.9%
			Total	108.1%
			Mean	21.6%

Time, hour	Sample	Original weight (W1), g	Weight after boil (W2), g	Water Absorption
8	G9	70.05	86.54	23.5%
	G10	68.58	84.52	23.2%
	G11	66.84	82.06	22.8%
	G12	71.03	86.56	21.9%
	G13	69.56	85.12	22.4%
			Total	113.8%
			Mean	22.8%

Time, hour	Sample	Original weight (W1), g	Weight after boil (W2), g	Water Absorption
10	H9	65.54	80.34	22.6%
	H10	70.52	85.86	21.8%
	H11	68.95	84.60	22.7%
	H12	69.53	85.13	22.4%
	H13	66.56	82.12	23.4%
			Total	112.8%
			Mean	22.6%

Time, hour	Sample	Original weight (W1), g	Weight after boil (W2), g	Water Absorption
12	J9	79.85	97.86	22.6%
	J10	80.12	97.65	21.9%
	J11	80.56	98.52	22.3%
	J12	81.50	98.75	21.2%
	J13	75.64	92.00	21.6%
			Total	109.5%
			Mean	21.9%

Time, hour	Sample	Original weight (W1), g	Weight after boil (W2), g	Water Absorption
14	K9	75.69	93.06	22.9%
	K10	74.65	91.2	22.2%
	K11	73.95	90.2	22.0%
	K12	74.56	90.84	21.8%
	K13	76.21	93.16	22.2%
			Total	111.2%
			Mean	22.2%

Appendix B: Result of flexural strength

Experiment 1 - Samples collected from local factory

Sample	Span (mm)	Width (mm)	Breaking Load (N)	Thickness (mm)	Thickness (mm^2)	Breaking Strength (N)	Flexural Strength (N/mm^2)
T1	75.00	63.10	76.00	6.95	48.30	90.33	2.81
T2	75.00	62.98	99.00	5.96	35.52	117.89	4.98
T3	75.00	64.90	170.00	7.06	49.84	196.46	5.91
T4	75.00	64.18	185.00	7.42	55.06	216.19	5.89
T5	75.00	63.70	105.00	6.13	37.58	123.63	4.93
						Total	24.52
						Mean	4.90
						Standard deviation	1.26

Experiment 2 - Samples fired at temperatures 900 ºc for four hours

Temperature, ºC	Sample	Span (mm)	Width (mm)	Breaking Load (N)	Thickness (mm)	Thickness (mm²)	Breaking Strength (N)	Flexural Strength (N/mm²)
850	A2	75.00	67.01	141.00	6.80	46.24	157.81	5.12
	A3	75.00	65.79	93.00	6.00	36.00	106.02	4.42
	A5	75.00	66.85	70.00	6.88	47.33	78.53	2.49
	A7	75.00	66.11	114.00	5.94	35.28	129.33	5.50
	A8	75.00	66.00	111.00	5.50	30.25	126.14	6.25
							Total	23.78
							Mean	4.76
							Standard deviation	1.43

Temperature, ºC	Sample	Span (mm)	Width (mm)	Breaking Load (N)	Thickness (mm)	Thickness (mm²)	Breaking Strength (N)	Flexural Strength (N/mm²)
900	B1	75.00	66.15	133.00	6.50	42.25	150.79	5.35
	B4	75.00	65.70	74.00	5.78	33.41	84.47	3.79
	B5	75.00	67.83	130.00	7.00	49.00	143.74	4.40
	B6	75.00	67.24	132.00	6.48	41.99	147.23	5.26
	B8	75.00	67.13	118.00	6.00	36.00	131.83	5.49
							Total	24.30
							Mean	4.86
							Standard deviation	0.73

Temperature, ºC	Sample	Span (mm)	Width (mm)	Breaking Load (N)	Thickness (mm)	Thickness (mm^2)	Breaking Strength (N)	Flexural Strength (N/mm^2)
950	B1	75.00	66.50	216.00	7.50	56.25	243.61	6.50
	B4	75.00	66.23	145.00	6.20	38.44	164.20	6.41
	B5	75.00	66.60	79.00	5.86	34.34	88.96	3.89
	B6	75.00	66.58	124.00	5.80	33.64	139.68	6.23
	B8	75.00	67.23	58.00	4.86	23.62	64.70	4.11
							Total	27.13
							Mean	5.43
							Standard deviation	1.31

Temperature, ºC	Sample	Span (mm)	Width (mm)	Breaking Load (N)	Thickness (mm)	Thickness (mm^2)	Breaking Strength (N)	Flexural Strength (N/mm^2)
1010	B1	75.00	65.93	127.00	5.40	29.16	144.47	7.43
	B2	75.00	65.83	136.00	5.86	34.34	154.94	6.77
	B4	75.00	65.89	114.00	6.08	36.97	129.76	5.27
	B5	75.00	65.41	105.00	5.80	33.64	120.39	5.37
	B6	75.00	64.80	153.00	7.06	49.84	177.08	5.33
							Total	30.16
							Mean	6.03
							Standard deviation	1.00

Temperature, ºC	Sample	Span (mm)	Width (mm)	Breaking Load (N)	Thickness (mm)	Thickness (mm²)	Breaking Strength (N)	Flexural Strength (N/mm²)
1050	B2	75.00	64.00	164.00	5.60	31.36	192.19	9.19
	B3	75.00	64.79	196.00	6.06	36.72	226.89	9.27
	B4	75.00	64.99	224.00	7.00	49.00	258.50	7.91
	B5	75.00	65.00	154.00	6.20	38.44	177.69	6.93
	B7	75.00	64.79	209.00	6.70	44.89	241.94	8.08
							Total	41.39
							Mean	8.28
							Standard deviation	0.97

Experiment 2 - Samples fired at temperatures 900 ºc at various hours

Time, hour	Sample	Span (mm)	Width (mm)	Breaking Load (N)	Thickness (mm)	Thickness (mm²)	Breaking Strength (N)	Flexural Strength (N/mm²)
6	F1	75.00	65.70	196.00	6.30	39.69	223.74	8.46
	F3	75.00	67.00	215.00	6.30	39.69	240.67	9.10
	F5	75.00	65.83	132.00	5.20	27.04	150.39	8.34
	F6	75.00	66.00	217.00	6.20	38.44	246.59	9.62
	F8	75.00	66.83	185.00	7.26	52.71	207.62	5.91
							Total	41.43
							Mean	8.29
							Standard deviation	1.42

Time, hour	Sample	Span (mm)	Width (mm)	Breaking Load (N)	Thickness (mm)	Thickness (mm²)	Breaking Strength (N)	Flexural Strength (N/mm²)
8	G2	75.00	66.95	140.00	5.10	26.01	156.83	9.04
	G3	75.00	65.75	234.00	7.00	49.00	266.92	8.17
	G4	75.00	65.50	220.00	7.40	54.76	251.91	6.90
	G7	75.00	66.20	384.00	7.44	55.35	435.05	11.79
	G8	75.00	64.80	207.00	7.16	51.27	239.58	7.01
							Total	42.92
							Mean	8.58
							Standard deviation	2.00

Time, hour	Sample	Span (mm)	Width (mm)	Breaking Load (N)	Thickness (mm)	Thickness (mm^2)	Breaking Strength (N)	Flexural Strength (N/mm^2)
10	H3	75.00	66.78	140.00	5.90	34.81	157.23	6.78
	H4	75.00	65.95	196.00	5.40	29.16	222.90	11.47
	H6	75.00	66.90	196.00	6.00	36.00	219.73	9.16
	H7	75.00	65.40	183.00	6.08	36.97	209.86	8.52
	H8	75.00	66.70	282.00	7.10	50.41	317.09	9.44
							Total	45.35
							Mean	9.07
							Standard deviation	1.70

Time, hour	Sample	Span (mm)	Width (mm)	Breaking Load (N)	Thickness (mm)	Thickness (mm^2)	Breaking Strength (N)	Flexural Strength (N/mm^2)
12	J4	75.00	66.75	180.00	6.28	39.44	202.25	7.69
	J5	75.00	65.80	301.00	7.12	50.69	343.09	10.15
	J6	75.00	66.20	199.00	6.16	37.95	225.45	8.91
	J7	75.00	67.20	140.00	5.14	26.42	156.25	8.87
	J8	75.00	68.10	373.00	7.38	54.46	410.79	11.31
							Total	46.94
							Mean	9.39
							Standard deviation	1.38

Time, hour	Sample	Span (mm)	Width (mm)	Breaking Load (N)	Thickness (mm)	Thickness (mm^2)	Breaking Strength (N)	Flexural Strength (N/mm^2)
14	K1	75.00	67.25	269.00	6.88	47.33	300.00	9.51
	K2	75.00	68.75	309.00	7.10	50.41	337.09	10.03
	K4	75.00	67.63	204.00	6.20	38.44	226.23	8.83
	K6	75.00	66.68	193.00	6.28	39.44	217.08	8.26
	K8	75.00	67.08	201.00	5.80	33.64	224.73	10.02
							Total	46.64
							Mean	9.33
							Standard deviation	0.78