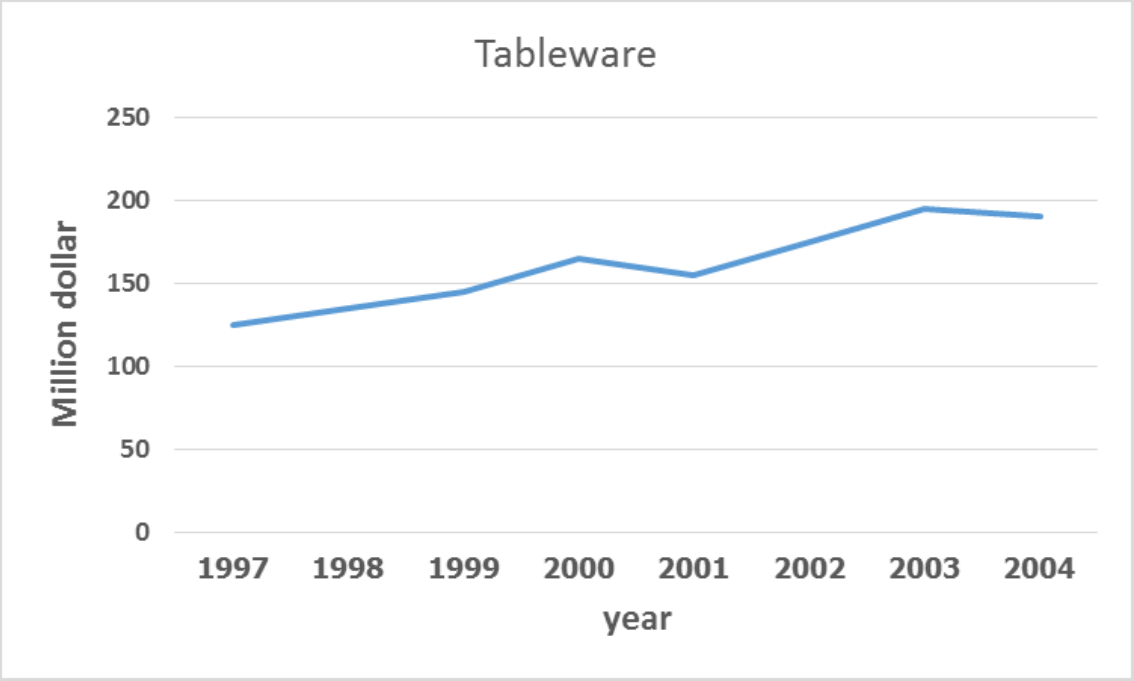
CHAPTER 2 FRONT END STUDY AND LITERATURE REVIEW

2.1 Introduction to Tableware Ceramics Industry

Exports of ceramics have been worth more than 20,000 million Baht which could be ranked the thirty fifth highest of exporting goods in 2001. As a result, employment in large, medium or small scaled industries (SMEs) had increased. Of all the whole industry there were about 63,000 employees hired. Compared to other countries in 2000, Thailand was ranked the eighth of the world for the countries that exported tableware. [16, 35, 36]

Figure 2.1 Tableware ceramics export between 1997-2004



Source: Department of international Trade Negotiation and World Trade Atlas [15]

Tableware Ceramics can be categorized into 4 types: [16,18,19]

1. EARTHENWARE is obtained under low firing temperature. The ceramics is thus porous which allows water absorption of about more than 5%. This type of ceramics is widely used because it is the cheapest.
2. STONEWARE is obtained with higher firing temperature than stoneware. Hence the ceramics is less porous than stoneware which allows about 3 to 5% water absorption.
3. PORCELAIN is made from a number of materials. After firing, a hard non-porous and translucent product of better quality than the first two is obtained.
4. BONE CHINA is the highest quality and the most expensive ceramics of the 4 types. It is delicate, highly translucent, but strong and no water absorption. As stated in the name, this type of tableware contains animal bone besides the raw materials used in porcelain.

Table 2.1 Cost Structure of Ceramic Production Costs

Production costs	%
Fixed cost	**45**
-Factory overheads	36
-Depreciation	9
Variable costs	**55**
-Raw material	21
-Energy -natural gas/LPG	13
-Labor cost	14
-Others	7

SOURCE: Division of Economical Industrial Condition Study 1, Ministry of Industry [15]

2.1.1 Historical Development

The oldest potteries, so far, in Thailand was found in a cave in Mae Hong Son province. They were earthenware dated back about more than 8,000 years.

Pattern was found in 2,000 – 4,000 years old earthenware. The pattern in the earthenware was simply inscribed and emphasized using red clay. The earthenware was still non-coated.

In the period of Lanna and Sukhothai there was an evidence of potteries exporting to other countries. There were constructions of ceramic kilns such as Turieng Kiln and Sri Satchanalai kiln.

In the reign of King Rama the third Chinese white ceramic came into popularity which caused the Thai ceramic development to be hampered.

In the reign of King Rama the fourth the Chinese white ceramic was brought to be patterned with Thai design using colors on glaze and gild surface called Benjarong porcelain and the well-known Lai Nam Thong.

In the reign of King Rama the fifth a lot of porcelain products from foreign countries were imported which resulted in the curtailment of Thai ceramic development.

In the reign of King Rama the seventh the remaining of ceramic productions were stoneware and Terra-Cotta for common household items.

After the World-War II period, there was a discovery of white clay source in Lampang province which was a turning point of the development Thai ceramic industry. The first ceramics factory was then started by a group of Chinese.

In 1961, the investment zoning in Samut Sakhon province according to the National Economic and Social Development Plan affected the relocation of ceramic factories. Moreover, there were imports of equipment and machinery of modern technology from Japan and Taiwan during the high expansion and growth. However, the production was mainly for local use.

During 1970-1979, there were joint ventures with the foreign countries, hence, European and American technologies were brought into use. Thai government focused on the measures and policies to give more support on the industry which led to more productions for exports.

During 1980-1989, there was a development of kilns from tunnel type into shuttle type due to the world oil crisis. Besides, the fast-burning technology was started to be introduced which signaled the starting period of expansion in Thai ceramics exports.

In 1990, it was the period of capacity expansion and product improvement for exports. It could be called exporting golden age with exporting value increasing from 788 million baht in 1986 to 7,768 million baht in 1996.

For the future trend, the manufacturers from the developed countries have turned to produce modern ceramics (new ceramics) and there may be a relocation of tradition ceramics production to countries in Indo-China[15,18,19]. Depending on the present capacity and capability, Thailand can reach the ceramic exporting value of 16,000-21,000 million baht with the export expansion rate of about 1-5% a year.

2.1.2 Future Trend

At present, Thailand is considered a leader in the production and market in ASEAN countries. There was an increasing exporting trend of 1-5% a year, and the exporting amount may reach about 23,600 million baht in 2008 [16, 36]. However, the role of China in the world market will be more important after joining WTO later in 2001 and the opening of ASEAN free trade area. Therefore, it is an important step in the preparation of Thai entrepreneurs to compete with China. According to low price Chinese products flooded into Thai market, in maintaining the leading role for the next ten years, there is a need of government support and cooperation in higher grade of product quality and design.

2.2 Target Market

Of all the ceramics products produced in Thailand, it was found that tableware had the most exporting value in 2001 (6,446 million Baht). The most important market in 2000 was the European Union, EU, (157 million USD); the second was the United States of America, USA, (133 million USD). In the EU market, tableware got the highest market share of all Thai ceramics exported and stoneware got the highest market share of all the tableware. However, in the USA, tableware was the second. Unlike the EU market, porcelain got the highest market share of all the tableware [15,36].

2.2.1 The market

It was found that, in the USA, Thailand was the leader on porcelain type tableware compared to the competitors like Spain and Italy. In the overview, the economic growth of the trading partner countries such as those in EU and USA is the most important factor that would bring about the export expansion of all products in all markets. The secondary factor is the competitiveness of Thai manufacturers. However, ceramics market in 2000 seemed to be rather little expansion growth and in some market there was even shrinkage.

The important ceramic export markets of Thailand are EU, USA, and Japan markets. The followings present and overview of each market [15,36].

American market, American market has had high demand of tableware ceramics which is varied from one area to another. There is market for high cost products. The market size is large and it is better than the EU market. In the USA market, competition is rather high. An important competitor is China. Although China has high skilled workforce, China has focused less on hand-made products than those from mass production. China started with the low price product in the low-end market and moving towards middle market. At present, ceramic products from China have been changing to get more market share of group B consumers. The invasion of low-end market products with the low-price strategy causes the products from China to have more market share than those from Thailand. As can be seen, in department stores, more products from China are displayed more than ceramics made in Thailand. Hence, Thai entrepreneurs encounter the pressure from the Chinese products. In the high-end market, products from Thailand cannot compete with those from the original market owner such as Italy.

The ceramic production capacity of medium and small-scale factories cannot supply the American market because each purchasing order is worth about 100 million Baht. However, there are some factories in Lampang province who have managed to cooperate and made it possible to supply the large amount order. Moreover, The gathering is not just ordinary manufacturers decided to work together but it is the gathering of hand-painted or hand-made production which meet the demand of American market or the consumers of group B+ and A who favor handicraft. China has not entered in this market segment because the purchasing orders are not much enough to catch an interest of or to suit the capacity of factories in China [15].

The European Union market, Most of the importers of EU place orders for the ceramic products from Lampang province because the ceramic products from China have been taxed higher than those from Thailand since January 1, 1996. The Cost Insurance Freight (C.I.F) price of products from China is higher than those from Thailand. Moreover, there is also a Quantitative Restriction (quota) of the ceramic tableware from China. However, as soon as China joins WTO, China will become an important competitor of Thailand because the Quantitative Restriction (quota) for the ceramic import from China will be cancelled. Additionally, the Most Favorite Nation (MFN) tax of China will become the same rate as Thailand.

Japanese market, It is a market demands for very high quality products. The Japanese are meticulous both in the type of ceramics and the design. It is, therefore, very difficult for the Thai entrepreneur to enter this market. Moreover, the size of Japanese market in 2000 was only 11.65 % of the American market, and 7.17% of the European Union market. In interviewing the trading companies of Japan it was found that in both the aspect of quality level and production level. it is not worth for the trading companies in Japan to work on the market, Thus, the Thai entrepreneurs can only deal with the small importers in Japan. [15]

Other markets, it is fortunate for Thai ceramic industry that the country is located in the center of the countries of Indo-China. It is possible to distribute the ceramic products especially the low-end products to neighboring countries. Besides, the sanitary ware producers who are making their trademarks known can also start their marketing in those neighboring countries. [15]

2.2.2 Customers and Customer Need [15]

The target customer of tableware ceramics is divided into 2 groups.

1. Domestic market, 30%
2. Foreign market, 70%

Domestic market can be divided into 2 groups:

1. Merchandiser sales the products to retailers, department stores, or kiosk for direct consumption by end users. The products for this group of customers are focused on pattern and design.
2. Company or organization has corporate sourcing procures the products for companies or organizations use. The group of customer places a big lot of order and sometimes with specified the company or organization design and/or logo. Quality and durability are the main requirements.

Foreign market is considered in 2 groups:

1. Individual end user buys products for daily use as well as for special occasion. Frequency of buying and quantity in each buy are not extensive. Design of the products is the main requirement.
2. Company or organization type of customer has the same requirement as stated in domestic market.

2.2.3 Customer Picture

The image of Thai tableware ceramics is considered to be intricate which reflects history, art and/or culture. The focus is not on modern technology but on the cultural value. The products are adapted to meet the needs of individual customer (Level of Customization). There is a big market for the high-end as well as high-touch customer group who has great purchasing power. Value added into products, especially the handicraft products, is still in demanded and will be for years because the demand side is much more than the supply side. If modern technology is applied to impart products with more function, value-added product will be achieved and more interesting.

2.3 Competitive Situation

2.3.1 Key Players

Local competitors, in 2004 there were more than 60 local producers of tableware ceramics in Thailand with total production capacity of 126,000 tons per year (Table 2.3) which is, among ASEAN countries, second to Indonesia. There were 8 out of the local producers who are big manufacturers with high production technology. The rest are medium-scale and small-scale producers scattering in Chiengmai, Lampang and Samut Sakorn province. [15]

Table 2.2 Top 10 of tableware ceramics producers in Thailand (information as of 2004)

Items	Tableware company
1	Royal Porcelain public co. ltd
2	Racha Ceramic Co.,Ltd.
3	Crown Ceramics Co.,Ltd.
4	Patra Porcelain co. ltd
5	Kasalong Ceramics co. ltd
6	IKEA Trading (Thailand) Ltd.
7	S.K.I. ceramics co. ltd
8	Patra Ceramic Co., Ltd.
9	Indra Ceramic Co., Ltd.
10	Eastern Chinaware Co., Ltd.

Source: Technology Center of Information and Communication by the co-operation of Customs Department 2004 [15]

International competitors

No ASEAN country is key player. Data in 2000 showed only 4 key players for tableware ceramics [15].

1. **China:** China is the most formidable competitor for both the porcelain and stoneware tableware products. The advantages are the low cost labor and materials.

2. **Italy:** Italy has the capability and capacity of exports of fine designed products that meet the needs of upper market (high-end product). Although Italy does not get the highest market share, the exporting value is the highest. Italy has advantages in the competition by not using the strategy of lower cost but breaking into the market with higher quality than competitors. The products with high quality aim at high-end market and the value per piece is rather high. As a result, Italy exports the products to Japan. The high margin is worthy. Hence, Italian entrepreneurs turn to produce more of the high-end products and the market share has been increasing.

3. **Spain:** Spain has started to be skillful in breaking into the porcelain and stoneware in Japanese market. Producers in Spain discovered the technique to make products that meet the requirement for Japanese market. Spain has then become another formidable competitor in Japanese market.

4. **India:** India has not been a competitor in all ceramics industry. However, India is a key player in only ceramics market in the Great Britain because of the relationships in the old days. India has got big market share for tableware porcelain type whereas Thai porcelain only gets market share of 4.22%.

2.3.2 Competition

Thailand ceramics industry is classified into 2 types of products that have difference in competition [15].

1. **Porcelain tableware**: the porcelain tableware market has the most intense competition among Thailand, China, Italy and Spain. Thailand has almost the same market share as Italy and Spain. However, in the EU market, Thailand has much more advantages than China because China is both limited by the importing quota from the EU market

and China has been cut off GPS (Generalized Special Preference) since 1996. It is possible, however, that after China becomes a member of WTO, China will increase its market share.[15]

2. **Non porcelain tableware**: the most formidable competitor is China because China gets more than 50% of the market share in American market and Japanese market. Later on, after China is the member of WTO, China will increase its market share rapidly. [15]

2.3.3 Current Offerings

The 60 local producers can be grouped as shown in Table 2.3. The Table presents different skills of each entrepreneur group. The organizations in each group can expand their growth and can get advantages over their competitors starting from their competencies.

Table 2.3 Competencies of ceramics industry groups in Thailand [15]

Group of ceramic industry	Competency
Chiangmai group	- Understanding of international market - Production capacity and capability, and marketing channels for artistic work and handicraft
Lampang group	- Efficient production - Flexibility in production which enable made-to-order products of desired quantity - Hand-paint products
Omnoi group	- Expertise in techniques for intricate ceramics - Expertise in painting both Benjarong and blue and white patterns
Saraburi group	- Modern factories. - Mass Production. - Advanced production technology - Production capacity supports big purchasing order - Marketing research for new requirement of both quality and design

2.3.4 Gaps

1. To develop products to meet qualifications of variety, identity and high value is an important approach to overcome the competition of the lower market which becomes more violent and intensive every day. For example, the containers which are applicable in the microwave oven and in the dishwasher, tourist souvenirs, celadon products which have been developed on the bluish green color to be the identity of Thailand and/or of each production area.

The information received from a big tableware ceramic factory which given by department of R&D that the company is developing clay material applicable for use of cooking food (can be used on stove top). The company see the possibility of exporting them but still there are problems about color development because it is hard to get stable color control.

2. Due to the relocation of the multinational corporations including the raw material and chemical suppliers along with the joint venture of final goods production can help upgrade the technology, marketing expansion, and wide knowledge as well as technology circulation in the country that can render the service of complete production chain

2.4 Key Technologies

The ceramic tableware industry in Thailand has the production of both large-scaled industry and medium and small-scaled industry. They have completely different production technologies which can be categorized into 2 groups:

The large scaled industry as in Saraburi province a high investment on machinery was put in especially automatic machinery for forming such as jigger, roller, computer Aids design with the R&D section and kiln technology for fast firing. [15,21]

The medium scaled and small scaled industry (SMEs) as Omnoi (Samut Sakorn), Lampang province and chiengmai province have problems on the standard control of production and also the standard of products. They also lack knowledge, experience and necessary tools for analyzing and testing. Besides, they face the quality problems, technical knowledge and ability on working techniques and problems on consistency control of the material divided according to the production steps. [15]

The production technology can be divided according to production process into 6 steps as the follower. [15]

2.4.1 Design Technology

The tableware ceramic product design in Thailand, at present, concludes both industrial design and art design. The problems that are mostly found in SMEs tableware ceramic product design is that the entrepreneur cannot apply the industrial design into the production process. As a result, it will take a long time to produce new products because rather much time is wasted to create a product prototype, master mold, mold for the work and also the production process testing prior to the real production. These problems can be solved by using the Computer Aids Design with the product designing to suit the production process. This technology can decrease time and steps in designing the master mold for the production process. Moreover, it can be applied for the reduction of factors causing lost in the production process. The designing technology being used at present can be categorized into 3 levels:

1. Pattern and color setting by using computer programming and being transferred on the work piece directly (Direct Transfer). This is usually used widely in the large-scaled company which produces tiles and dishes. They can afford the investment on machinery and computer programs.
2. Pattern and color setting by using computer programming or by hand and then printing it on the transferring plate or the ceramics sticker. Subsequently, the sticker is put on

the work piece before being baked to get the required color and pattern. This is usually used in the SMEs.

3. The pattern and color is mostly done by hand. It is directly painted on the work piece. By this way it cannot be a mass production in a short time but it is a potential decoration way that can add highest value. This is usually used in the SMEs.[15]

2.4.2 Processing of Raw Materials Technology

The technology in the processing of raw materials as required for the tableware products is not complicated and the equipment can be locally provided but he problem on the raw material preparation that is found is that the raw material has no consistency on quality. Especially, the medium and small-scaled factories mostly have not full knowledge of the raw material properties, so they cannot apply the appropriate raw materials and also they lack basic knowledge to process the raw materials to the required properties. However, even though many entrepreneurs understand the technology but lack testing tools necessary for the quality control in the processing of raw material preparation, and/or they have difficulties to get that testing service because of the complicated steps or the slow service. All things considered, this group of entrepreneurs is counted to have potentiality and should be promoted and supported. [15]

2.4.3 Forming Technology

At present the wet forming such as Ram Press, Roller, Jigger and Pressure Casting and Slip Casting are the most popular in tableware production because it has been long and popularly used, but the problems found mostly for SMEs is the lack of basic knowledge and understanding in the learning process and technology transferring that cause most of the entrepreneurs not to be able to control the defects on the products using this forming process. Besides, the future environment can be a problem because of the used plaster mold which is in big number. The thing is in wet forming in this industry, the molds are in great number and they can be used not more than 200 times; therefore, there should be a way to recycle them or to dispose them well or apply them to other work instead of piling them as garbage mounds.

The recently used forming technique in the passing 10 years, the main method is Dry Pressing, is done by using mold made of metal or polymer material and the forming technique using high pressure (High Pressure Casting) in which Resin mold with high porosity is used. These two technologies can reduce the use of molds and it suits the production industry of mass products in the same pattern. However there is still a limitation on the designs that can use these forming techniques. Besides, there must be a mass production of each pattern. Moreover, the investment on the machinery and molds are very high. [15]

2.4.4 Kiln Technology

Ceramic is an industry that uses high quantity of energy in the production process; therefore, the efficient kiln technology is interesting to the developers both in the government sector and private sector. However, the good technology is available only in the large factory with high investment. The medium and small-scaled factories cannot get that technology. They can get only locally-made kiln due to the limited budget. As a result, it is interesting to develop the medium and small-sized kilns of good quality with low budget. [15]

2.4.5 Decoration and Glazing Technology

To paint by hand or to pattern is an outstanding feature and advantage of ceramic tableware industry because Thailand is a country that has a long history of culture as an identity with skilled workers and highly artistic conceptual thinking. Consequently, the production of ceramics with pattern painting can be used for winning the competition in the world ceramic industry. At present for glazing there are many ways of doing it such as dip, spray or paint by hand and by machine. Generally, to get the evenly consistent coating, the glaze and stain color being used has to be mixed in the right proportion as in the formula as the objective set which are both being researched by the factory and by the government sector who develop it for the service to the industry sector. [15]

2.4.6 Logistic Technology

At present there has been an increase of the use of computer technology and information technology, for example, the buyer can place order and follow up the production situation of the products through internet. However, the SMEs have not used this system in their business development neither in the type of Business to Business: B2B nor the type of Business to Customer: B2C [15]

2.5 Opportunity Development

The problems of tableware ceramics industry were observed and studied, both needed propitiation technology and recent industrial conditions. There are opportunities to be in ceramic tableware industry as follows:

2.5.1 Opportunity Development for material

1. **Production of raw material of ready-made clay that has unique property appropriate for using with electric and gas appliances for cooking.** It was found that we can develop appropriate material for the cooking usage which corresponds to the cooking behaviors of the foreigners that are using the microwave in warming food and electrical stove or oven in cooking food. At present the products in the group of ovenware have a good share of marketing.[17] There are four types of materials: metal, plastic, glass and ceramic. We will find that food containers made of glass and ceramic can be used in cooking and warming food with electric appliances in daily life. In addition to fundamental information we can find the chance to develop ceramic clay content applicable to the cooking of food, warming food and holding food for eating that has the property of thermal change resistance. It can be produced by the existing production methods and technology that the SMEs of the Thai ceramic tableware have in order to develop the competitive potentiality in the world market; and moreover, it will be a publicity of Thai culture and identity through tableware ceramics.

2. **The development of ready-made clay with properties to the market need but with energy reduction in firing.** From the analysis of the tableware industry structure it is found that energy cost proportion is 5.20% of all the total cost. At present energy material is a world problem that every industry is facing. In the tableware production process there must be three times firings which waste a lot of energy. Accordingly, the opportunity in ceramic tableware production development that can save energy becomes an interesting issue**.**

3. **The development color stain from local raw material.** From the data analysis in decoration industry it was found that most of the chemicals and colors have been imported from foreign countries up to 90% which is another part that should be developed to get local production.

4. **The production of ceramic tableware from raw materials that can be replaced 100% or recycling materials from industry waste**. The review showed many researchers having tried to recycling the industry waste into use as raw materials for ceramics industry such as silica from rice husk or fly ash.

2.5.2 Opportunity Development for Recycling management

1. **The development of management on destroying process of plaster molds with correct method or the recycling of the plaster molds for reproduction.** The environment problem that clearly happens from the industry is from the waste left from the production process especially the plaster molds. The problem that follows is that those plaster molds have absorbed many kinds of chemicals from the soil content. If these plaster molds are not rightly managed, there will be problems especially on the law concerning environment.

2.5.3 Opportunity Development for technology

1. **The development of high efficient oven which save energy in firing or the production of oven using alternative energy of lower cost.** Kiln is another factor which is essential in ceramic industry. At present the medium-scaled and small-scaled factories have not enough capital to have the high efficiency kiln for the production of work pieces. The problems found are that the entrepreneurs use imported second-handed kilns from other countries and the quality of the kiln is not good and affects the quality of the work pieces to be inferior as well.

2. **The development of products of new functions by blending between modern technology and advanced ceramics in the production process.** From the suggestions made to the product development of the large-scaled factories both inside and outside the country, advance ceramics technology has been brought into use to create new supplementary function to the ceramic tableware such as the content property development of the products to be durable against the fracture or chipping done by Correlle Company Limited.

2.5.4 Conclusion

For the opportunity development with the interview information from a big ceramic ware company (Racha Ceramic Co., Ltd) which given by department of R&D that the company has a plan to develop clay material applicable for use of cooking food (can be used on stove top). The company see the possibility of exporting. This information show the trend for development ovenware ceramics in the term of decrease sintering temperature and industry waste recycling.

2.6 Preliminary Product Design Specifications

From the front end study and ceramic company interview show the preliminary specification as the follow.

1. White color.
2. Easy to clean.
3. Water absorption was below 1%.
4. COE was below 4-5 x 10^{-6} ° C^{-1}
5. Withstanding of sharp change of temperature from 150 Celsius in the oven into cold water immediately JIS S 2400 [10].
6. Sintering at 1250° C.
7. Passing TIS 601-2546 Ceramic Containers for Food: Earthen ware [26].
8. Forming and firing can be done by middle and small-sized entrepreneurs.

2.7 Thermal shock resistance [25]

Most materials can withstand sudden temperature change only to a certain extent, failure occurring when the temperature gradient that has been set up exceeds a given value. Such failure often occurs in a complicated way, it is governed not only by the nature of the material but also Mechanical Strength, thermal conductivity, linear coefficient of thermal expansion, modulus of elasticity shape, etc. It has been become very much more important recently when the use of ceramic refractories in gas turbines, rocket motors and nuclear reactors is under consideration

2.7.1 Factors which affect the sudden change of temperature

1. Mechanical Strength [12]
2. Thermal Conductivity [12, 25]
3. Coefficient of Thermal Expansion [19, 24]
4. Modulus of Elasticity [24]
5. Thermal Diffusivity [12]
6. Refractoriness [12, 7]
7. Porosity [12, 7]
8. Specimen Size and Shape [24, 14]

2.7.2 Thermal shock resistant material [24, 20]

The thermal shock resistant material means the material that can tolerate when it receives high heat and is cooled down rapidly, or the material is being cooled down and receives the heat rapidly which results in cracking and damaged. The thermal shock resistant materials used in ceramic production as seen in Table 2.4, when the information on thermal shock resistance which is indicated as R value it is seen that any material that R value is high will be the material that has lowest coefficient value of extension from heat (α). In Table 2.4 it shows the α value decreased from <0.5 ×10^{-6} °C^{-1} of spodumene to 0.5×10^{-6} °C^{-1}, 1.7-2.0×10^{-6} °C^{-1}, and 4.0x10^{-6} x10^{-6} ˚C^{-1} of fused silica, cordierite and mullite, respectively.

From Table 2.4 it is found that mullite has low coefficient value of extension of 4.0 × 10^{-6} °C^{-1} but it has rather low value of thermal shock-resistance of 123-300°C. Consequently, if it is brought to produce the thermal shock-resistant material, it can be cracked or damaged. For this reason another material with the coefficient value of extension with low heat is considered to be mixed. This material is cordierlite (α = 2 ×10^{-6} °C^{-1}) and it also has high value of thermal shock-resistance which is 300-500°C. Consequently, the

cordierlite synthesis is the objective of this study for the benefit of being applied in the future production of thermal shock-resistant material. [25, 30]

Table 2.4 Physical property and Thermal shock Resistance of material [25, 30]

Material	**Strength (MPa)**	**Modulus of Elasticity (× 106 MPa)**	**Coefficient of Thermal Expansion ($\times 10^{-6}$ °C^{-1})**	**Melting Point (°C)**	**R (°C)**
Spodumene	137.82	0.068	<0.5	1389	1000
Fused Silica	29.4	-	0.5	1710	600
Cordierite	26.2	0.082	1.7-2.0	1540	300-500
Mullite	89.6	0.145	4.0	1810	123-300
Zircon	103.4	0.137	4.0	2550	150
Beryllium Oxide	-	0.061	8.9- 9.0	2525	-
Alumina	310.1	0.351	8.9-9.0	2050	96
Spinel	96.4	0.234	8.0-9.0	2135	-
Graphite	48.2-68.9	0.234	8.0-9.0	3650	100
TiC Cermet	413.5	0.413	7.4	2655	-
Forsterite	137.8	-	9.5	1890	-
Silicon Carbide	172.3	0.024	4.7	2300	230

2.7.3 Phase forming of Thermal shock resistance

Cordierlite ($2MgO.2Al_2O_3.5SiO_2$) is a chemical compound of Magnesium Aluminum Silicate were synthesis from Aluminum Oxide, Talc and Clay. The starting raw material of Cordierlite and Cordierlite mineral are Magnesium-Alumino Silicate, Dichroite and Iolite. Cordierlite has low COE, high value of mechanical strength, low value of dielectric. Due to its good property in dielectric, cordierlite is brought into production of insulator or insulating substrate. Besides, because it has the property of high value in thermal shock-resistance. [4]

Cordierlite from nature is in low quantity which is not sufficient for the use in industry. Thus, Synthesis is needed by using the raw material ratio as close as the elements of Cordierlite in the theory. In the synthesis of Cordierlite, many researchers use many kinds of raw material.Cordierlite synthesis will be obtained from preparation of two different group of raw materials.

1) The commercial grade raw material is normally categorized into 3 groups as follows: [11, 17, 18]

- Clays, material with sticky property such as Nature clay, Kaolin, China clay
- Fluxes, raw material without sticky property such as Talcum (Talc).
- Fillers, raw material without sticky property such as Alumina

2) The waste raw material such as Fly Ash and Anodizing slug. [21]

For example, Jackson [11] prepares Cordierlite from Talcum 43%, plastic clay 35% and $A1_20_3$ 22%. The sample has low value of the co-efficient of thermal extension at 0.53 x 10^{-6} $°C^{-1}$ at the temperature between 0-200°C. It is also found that sample prepared from the mixing of Steatite Talc, $A1_20_3$ and clay has the co-efficient of thermal extension higher than the one, Moreover , the sample prepared from Perchlorite and Kaolin will have the co-efficient of thermal extension at 0.23 x 10-6 $°C^{-1}$ the lowest than the all. Cordierlite prepared as stated above is close to the Cordierlite in the theory $2MgO.2A1_20_3.5Si0_2$ which is the composition of MgO 13.7%, Al_2O_3 34.9%, SiO_2 51.4 %. Lamar, et al. [14] produced Cordierlite applied from Jackson, the mixture of Steatite-Talc 45%, White clay from Florida 35% and Corundum 25% it is found that there is the co-efficient of thermal extension at 0.50 ×10-6 $°C^{-1}$ from the room temperature to 0-200 °C that lower than the Jackson.[11]

There have been many researchers that have studied on the synthesis of Cordierlite. And Cameruccii, et al. (2001) [4] are interested in the synthesis of Cordierlite focusing on the size of the material as a main consideration in order to study the mechanism of density by using commercial Cordierlite(CORCR Baikowski, France). The phase diagram are $A1_20_3$. $Si0_2$.MgO. The phase composition show α-cordierlite to be the main phase and also found secondary phase of Mullite. From the study it is found that at the sintering temperature of 1400 °C there will be the phase of Mullite with density at 66.41%. When increase the temperature to 1450 °C there will be the phase of Cordierlite, Mullite and glass with density at 94.16% .It can be confirmed with the observation the porosity value on the SEM photo. From the stated behaviors it can be explained because there is a big quantity of liquid occurring at the temperature of 1450 °C. Thus, it can be concluded that the mechanism of density is the type of liquid Sintering, and the density can improve by the reduction of particle size if it is single fraction. But for the binary mixture there must be the mixture of smaller atom of 50% of weight to get high value of density. R. Goren et al., (2006) [31], was synthesized cordierite by using a composition prepared by the mixture of four different materials: a talc, fly ash, fused silica and alumina by taking all the four kinds to weigh for the mixture ratio of 2MgO.2Al2O3.5SiO2 and ground for 8 hours subsequently brought to form by pressing. After sintering it at different temperature of 1200, 1300, 1350 and 1375 °C respectively then examined for the mineral elements. The mechanism to get Cordierlite is the sintering reaction of solid –state sintering which will occur at the temperature of 1350 °C after sintering for 1 hour. From the experiment it is found that sintering at 1350 °C for 3 hours will give result of mineral elements the same as sintering at 1375 °C for 1 hour but only α-Cordierite is found. As a result it shows that time duration is essential for the phase occurring of Cordierlite. From the stated reference there is a concept to produce the mixed materials of Cordierlite and Mullite with good property that are with high value of strength, with the co-efficient value of extension with low heat , with the property of thermal shock-resistance and with durability against chemical erosion. Ghitulica et al. [32] prepares Cordierlite by alumina with other raw material and ground for 4 hours. After sintering it at temperature 1050-1400 °C. At 1200 °C XRD present phase composition of cristobalite silica and cordierite phase were form at the temperature higher than 1300°C.

Moreover, many researcher improve the thermal shock property by used spodumene such as J. Garcia-Ten et al., (2000) [33] Present the property of spodumene has a melting temperature of 1420 °C, density of 3.2 g/ cm. and Mohs hardness of 6.5 to 7. Spodumene has been used as a flux in various traditionally ceramic products. Moreover Spodumene has high refactory and low expansion compare with the other feldspar and has been used

in flameproof body [7]. S. Peterson (1992) [34] and P. Pimkhaokham (2004) [19] used 20% of spodumene with the other raw material to produce flameware at 1285 ˚C

2.7.4 Conclusion

The literature review showing the trend for development ovenware ceramics in the term of decrease sintering temperature by 1) Raw material selection 2) Blending time 3) Spodumene adding and 4) Replace the commercial grade raw material by industry waste recycling raw material.(Detail in chapter 4)