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THE EXPERIMENTAL DESIGN AND CARBON FOOTPRINT ASSESSMENT OF NON-GLAZED FLOOR TILES

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ABSTRACT: Carbon emission from the manufacturing sector is a critical issue which is concerned by the environmental authorities since the violation of the carbon emission cap might lead to the sanction by one of Thailand's largest trade partner, European Union (EU). As a result, it is important for the manufacturers to be able to assess their own products' carbon footprint. In this study, the selected case study is a ceramic factory which manufactures non-glazed floor files. The scope of evaluation covers Business-to-Customer (B2C) transaction while the life cycle of a product includes four stages, i.e., resource extraction, manufacturing, distribution, use and waste disposal. The study results indicate that the highest contribution to the carbon emission is from the extraction of ceramic clay while the manufacturing stage has the second highest effect on the emission. The distribution of products, use and disposal are the life cycle stages which have small effects on the emission. Another objective of this research is to conduct an empirical study which leads to the capability to quantify the effect of different factors on the manufacturing of floor tiles. According to the experimental study, three factors, i.e., chalk clay, ball clay and feldspar, are considered as the process inputs while the response variables are percent absorption and hardness. Elaborately, 2^3 full factorial design was deployed to study the find the relationship between inputs and outputs. The results has two folds. The first fold is useful for the manufacturers who would like to understand how much their product has emitted the greenhouse gas to the atmosphere and it might lead to the minimization of their emission. Moreover, the relation between the tile characteristic and factors affecting the manufacturing is known so the manufacturer is able to efficiently optimize the manufacturing process in order to achieve the highest quality products.

Keywords: Business-to-Customer, Carbon footprint, Design of experiment, Life cycle, Non-glazed floor tile.

1. INTRODUCTION

Greenhouse gas (GHG) emission is the critical issue which is on the spotlight of the world community since it is one of the possible causes of the world’s climate change. There are initiations from developed countries to address the issue and also the resolution to reduce the emission. European Union (EU) is among the very first group of nations which create the awareness by issuing the carbon credit and carbon footprint schemes. On the other hand, President Barack Obama of the United States has declared in 2015 that the US will decrease the emission for one-third by reducing the emission from power generation which is based on coal-burning power plants. For the emerging economies like Southeast Asian countries, Thailand is one of the leading nations which is aware of the carbon footprint issue since it has the official organization body (Thailand Greenhouse Gas Management Organization or TGO) which is responsible for managing the GHG emission in Thailand. As a result, the manufacturers in Thailand have the guidelines for calculating the carbon footprint of their products and the assessment will lead to the awareness of the average emission per functional unit to the atmosphere.

Among many industries, ceramic manufacturing is among the industries which are responsible for the emission of a large amount of GHG in Thailand. According to the report by the European ceramic industry association, the emission due to the ceramic production will be reduced if all the kilns used in the industry are improved to fire products efficiently [1]. In 1998, the National Pollutant Inventory unit of the Queensland department of environment issued the emission report for bricks, ceramics, clay and product manufacturing [2]. Quinteiro, Araujo, Oliveira, Dias and Arroja [3] conducted a study to compute the GHG emission of different ceramic earthernware pieces. Similarly, Quinteiro, Almeida, Dias, Araujo and Arroja [4] had extended their research in 2012 to cover other ceramic products, i.e., brick, roof tile, wall, floor tile and sanitary ware. Peng, Zhao, Jiao, Zheng and Zeng [5] have calculated the CO_2 emission and also suggest the options to reduce the emission in a ceramic tile manufacturer. For construction purpose, Sazedj, Morais and Jalali had compared the CO_2 emission from two types of materials, bricks and concrete block [6]. Bribian, Capilla and Uson [7] also studied the energy demand and CO_2 emission among different construction materials which are ceramic, steel, PVC, wood, mortar, cement, aluminium and lime. The gas release during firing of clay to produce bricks was studied by Toledo, Santos, Faria, Carrio, Auler and Vargas [8]. In this study, the experiment was conducted to examine the amount of emission at the different temperatures.

According to the literature, the emission from the production of different ceramic products is studied while the focus is on the construction materials. However, the emission from small manufacturers seems to be ignored even it also contributes a large portion on the emission since, in Thailand, most ceramic manufacturers are small and medium enterprises. The awareness regarding the emission is important to both manufactures and consumers. The selected case study for the emission assessment in this research is the emission from the whole life cycle of a ceramic product, non-glazed floor tiles manufactured in a small factory. Elaborately, the emission from each stage of the life cycle is profoundly analyzed and calculated. Moreover, the study also points out the hotspot which is highly contributed to the major emission. Last but not least, the recommendation for the reduction in the emission is also addressed and discussed.

2. MANUFACUTRING PROCESS

According to the study, the instructions by Thailand greenhouse gas management organization (TGO) are carefully followed while the evaluation is based on the transaction of B2C (businesss-to-customer). A product chosen as a case study in this research is a non-glazed floor tile as shown in Fig. 1. The weight of a floor tile (functional unit) is 0.225 kg. The main ingredient of the floor tile is the clay excavated from the area of Lampang province (Fig. 2 and 3). Other ingredients are Feldspar (20% of the floor tile weight = 0.045 kg) and Kaolin (20% of the floor tile weight = 0.045 kg). The production facility is located in Prathumthani province. The kiln used for firing tiles is illustrated in Fig. 4 and the source of fuel for this kiln is liquefied petroleum gas (LPG). Another important aspect for the life cycle analysis is the clarification of manufacturing process. For producing floor tiles, the manufacturing process consists of the following steps, starting from mixing clay, Kaolin and Feldspar. The next step is forming and finishing, biscuit firing and glost firing. All the process is concluded in a flow chart in Fig. 5.

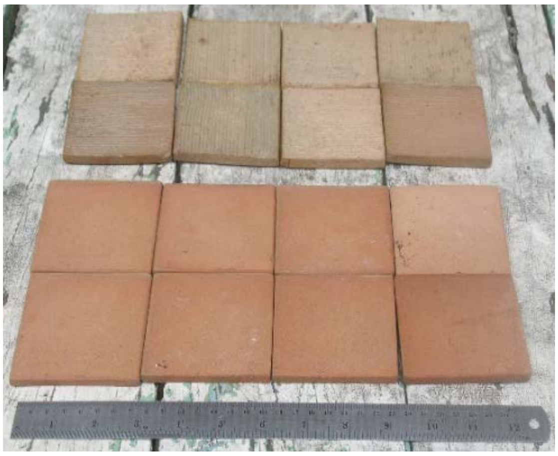

Fig. 1 A sample of floor tiles.

Fig. 2 Excavation site.

Fig. 3 Excavation.

Fig. 4 Kiln fuelled by LPG.

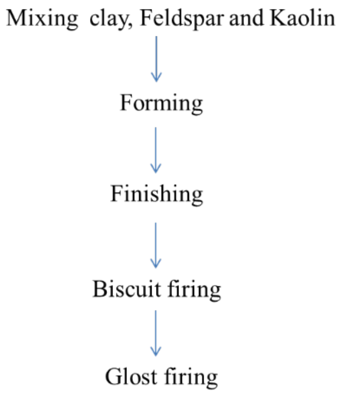

Fig. 5 Manufacturing process.

3. LIFE CYCLE ANALYSIS

The life cycle analysis of non-glazed floor tile is differentiated into five stages, resource extraction, manufacturing, distribution, use and waste disposal.

3.1 Resource Extraction

The main ingredient of the floor tile in this research is the clay excavated from a paddy rice field which is located in Lampang province. Other two ingredients are Feldspar and Kaolin and their emission analysis is shown in Table 1 which illustrates the quantity in weight per unit and emission for each ingredient.

Table 1 GHG emission of raw materials extraction

Raw Materials	Quantity (kg)	EF ($kgCO_2$ eq/kg)	Emitted GHG ($kgCO_2$ eq)
Clay	0.135	-	-
Feldspar	0.045	0.8635	0.03886
Kaolin	0.045	0.2167	0.0097515
Total			0.0486115

Another important source of emission which cannot be ignored is the emission due to the transportation of raw materials to the factory. After the excavation, the clay is shipped to the factory which is located in Prathumthani province by a ten-wheeled truck with the maximum load of 16 ton. The distance between the factory and the source of clay is 568 km. On the other hand, other ingredients (Feldspar and Kaolin) are transported from a supplier in Bangkok by a four-wheeled truck with the maximum load of 75% of 7 ton. The supplier's warehouse is 65 km from the factory. The computation is separated into two parts, delivery and return. In Table 2, the load of the transportation is illustrated in the form of tkm unit. The GHG emission of the transportation of raw materials for the delivery trip is shown in Table 3.

Table 2 Load of raw material (delivery)

Raw Material	Quantity (kg)	Distance (km)	Load (tkm)
Clay	0.135	568	0.07668
Feldspar	0.045	65	0.002925
Kaolin	0.045	65	0.002925

Besides the delivery of raw materials, the emission from the return trip of the trucks has to be included in the calculation as shown in Table 4 and 5. For the return trip, the maximum load of the mean of transportation must be included in the calculation as recommended by TGO. For example, the load of clay is equal to 0.135*568/(1000*16) = 0.0047925 tkm.

Table 3 GHG emission of the transportation of raw materials (delivery)

Raw Material	Mean of Transportation	EF ($kgCO_2$ eq/tkm)	Emitted GHG ($kgCO_2$ eq)
Clay	Ten-wheeled Truck (max load: 16 ton, 100% Loading)	0.0451	0.003458268
Feldspar	Four-wheeled Truck (max load: 7 ton, 75% Loading)	0.239	0.000699075
Kaolin	Four-wheeled Truck (max load: 7 ton, 75% Loading)	0.239	0.000699075
Total			0.004856418

Table 4 Load of raw material (return)

Raw Material	Quantity (kg)	Distance (km)	Load (tkm)
Clay	0.135	568	0.0047925
Feldspar	0.045	65	0.000417857
Kaolin	0.045	65	0.000417857

Table 5 GHG emission of the transportation of raw materials (return)

Raw Material	Mean of Transportation	EF ($kgCO_2$ eq/tkm)	Emitted GHG ($kgCO_2$ eq)
Clay	Ten-wheeled Truck (max load: 16 ton, 0% Loading)	0.5711	0.002736996
Feldspar	Four-wheeled Truck (max load: 7 ton, 0% Loading)	0.3324	0.000138895
Kaolin	Four-wheeled Truck (max load: 7 ton, 0% Loading)	0.3324	0.000138895
Total			0.003014786

The total emission of the raw materials regarding the delivery and return trip is concluded in the following Table 6 and 7.

Table 6 GHG emission of the transportation of raw materials

Raw Material	Emitted GHG ($kgCO_2$ eq)		
	Extraction	Transport Delivery	Transport Return
Clay	-	0.003458268	0.002736996
Feldspar	0.03886	0.000699075	0.000138895
Kaolin	0.0097515	0.000699075	0.000138895

Table 7 Total GHG emission of the transportation of raw materials

Raw Material	Total Emission ($kgCO_2$ eq)
Clay	0.006195264
Feldspar	0.03969797
Kaolin	0.01058947
Total	0.056482704

3.2 Manufacturing

The manufacturing process basically depends on firing floor tiles and it is expected to be the main source of GHG emission. The fuel used in the kiln is liquefied Propane gas (LPG). The emission due to LPG is divided into two substages, acquisition and use. The emission factors for acquisition and use are 0.4116 and 0.4122 $kgCO_2$ eq/kg respectively. The LPG use is for two processes, biscuit firing and glost firing. The total emission due to the manufacturing is shown in Table 8.

Table 8 GHG emission of the manufacturing (LPG use)

Resouces	Process	Quantity (kg)	EF ($kgCO_2$ eq/kg)	Emitted GHG ($kgCO_2$ eq)
LPG	Biscuit Firing	0.2	0.4116 + 0.4122	0.16476
LPG	Glost Firing	0.3	0.4116 + 0.4122	0.24714
Total				0.4119

3.3 Distribution

Since the distribution stage solely relies on the transportation, the computation of GHG emission is similar to the shipment of raw materials to the factory. After the manufacturing stage, floor tiles as the finished product are shipped to the Chatuchak Sunday market which is 75 km away from the factory. For the delivery trip, the emitted GHG is calculated as shown in Table 9 and 10 respectively.

Table 9 Weight and distance per unit of floor tile (delivery)

Product	Weight (kg)	Distance (km)	Load (tkm)
Floor tile	0.225 (1Piece)	75	0.016875

Table 10 GHG emission due to the delivery per unit of floor tile

Product	Mean of Transportation	EF ($kgCO_2$ eq/tkm)	Emitted GHG ($kgCO_2$ eq)
Floor tile	Four-wheeled Truck (max load: 7 ton, 100% Loading)	0.1402	0.002365875

On the other hand, the return trip for a truck has emitted the amount of GHG gas as shown in the following Table 11 and 12 while the total emission is depicted in Table 13.

Table 11 Weight and distance per unit of floor tile (return)

Product	Weight (kg)	Distance (km)	Load (tkm)
Floor tile	0.225 (1Piece)	75	0.0024107143

Table 12 GHG emission due to the return trip per unit of floor tile

Product	Mean of Transportation	EF ($kgCO_2$ eq/tkm)	Emitted GHG ($kgCO_2$ eq)
Floor tile	Four-wheeled Truck (max load: 7 ton, 100% Loading)	0.3111	0.0007499732

Table 13 Total GHG emission regarding the transportation

Product	Emitted GHG ($kgCO_2$ eq)		Total Emission ($kgCO_2$ eq)
	Transport Delivery	Transport Return	
Floor tile	0.002365875	0.0007499732	0.0031158482

3.4 Use

Approximately, floor tiles are cleaned monthly to remove dust, mud and fungi. Water spray is used to clean the surface of floor tiles. The amount of emission regarding the use is shown in Table 14.

Table 14 GHG emission due to the use

Resource	Quantity (kg)	EF ($kgCO_2$ eq/unit)	Emitted GHG ($kgCO_2$ eq)
Water	0.2	0.0003	0.0006

3.5 Waste Disposal

Since this type of floor tiles is non-glazed and no additional color is applied to the tiles (earth tone), the recycling rate is almost 100 percent. Therefore, there is no GHG emission in this stage.

3.6 Overall emission

Due to the life cycle analysis, the total emission of each stage is shown in Fig. 6 and 7 consecutively. Most of the emissions fall into the category of resource extraction and manufacturing process. The implication is that the large portion of contribution on the emission is caused by the raw material supplier and manufacturer. Since the manufacturing process depends on the firing by using LPG, the acquisition and use of fossil fuels is the main source of emission in this case.

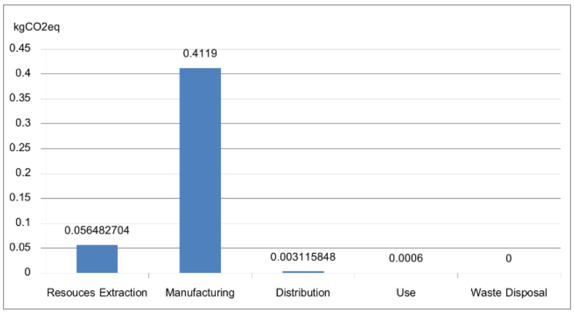

Fig. 6 Elaborated GHG emission by each category.

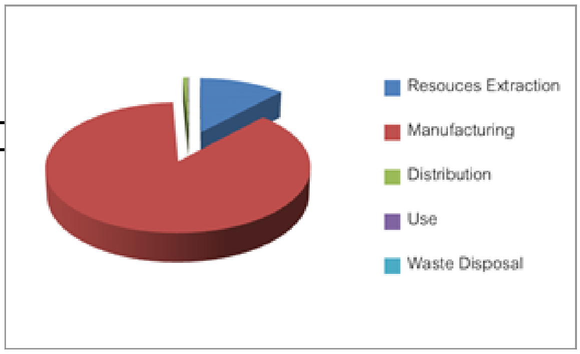

Fig. 7 Overall GHG emission by category.

The transportation of raw material to the manufacturer and the shipment of finished goods to the market also rely on the fossil fuel. Therefore, if there is a reduction in the use of fossil fuel, it will significantly decrease the GHG emission to the atmosphere. On the other hand, if the alternative source of energy besides fossil fuel with low GHG emission is explored and used, it will lead to the reduction in the carbon footprint of the whole process as well.

4. DESIGN OF EXPERIMENT

The 2^k factorial design of experiment is deployed to study the effect of three factors' ingredients, ball clay (A), Kaolin (B), Feldspar (C) on two crucial characteristics of tiles, namely, rate of water absorption and hardness. Table 15 illustrating input factors and their levels are shown as follows:

Table 15 Factors and their levels

Factor	High (1)	Low (-1)
Ball Clay(A)	10%	30%
Kaolin (B)	5%	20%
Feldspar (C)	10%	20%

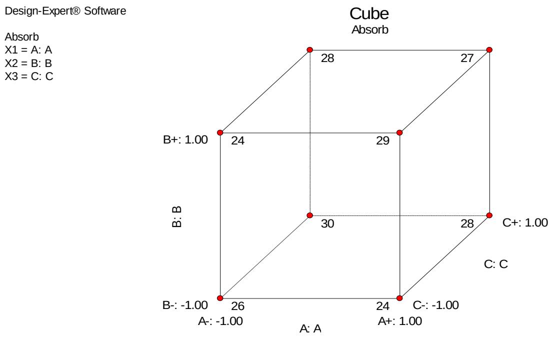

Fig. 8 Cube plot for rate of absorption rate.

If the interested characteristic is the rate of water absorption, the statistical analysis indicates that there is a three factor interaction (ABC) among all three factors (ingredients), Ball Clay (A), Kaolin (B) and Feldspar (C). According to the cube plot in Fig. 8, floor tile will have the low water absorption rate when the percentage ingredients of each factor are set at the following levels:

-A (low), B (high), C (low) and

-A (high), B (low), C (low).

For the hardness, the result in Fig. 9 obviously shows that there is an interaction between Kaolin (B) and Feldspar (C). The important finding is the percentage of Kaolin is high (20%), it will result in the reduction of the hardness of the floor tile no matter the Feldspar component is set at the low or high level.

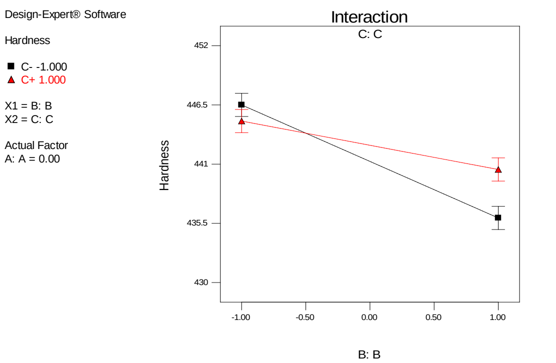

Fig. 9 Interaction plot for rate of water absorption.

5. CONCLUSION

This objective of this research has two folds, the life cycle analysis and the conduction of experimental analysis which leads to the desired characteristic of floor tiles. For the life cycle analysis, the manufacturing fraction seems to mostly contribute on the greenhouse gas emission. Therefore, the process improvement should focus on the reduction of emission from the activities of the manufacturing process. According to the experimental analysis of the desired characteristic, the result shows that there are interactions among two and three factors which affects the rate of water absorption and hardness of floor tiles.

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