A STUDY ON PROPERTIES OF LIGHTWEIGHT BRICK USING PLASTIC WASTE AS FINE AGGREGATES

EMWIKA PIAMSUK

NATTHAKAN MANATSA

PAWIGA SIHAWONG

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Special project topic	A STUDY ON PROPERTIES OF LIGHTWEIGHT BRICK USING PLASTIC WASTE AS FINE AGGREGATES
Student	Ms. Emwika Piamsuk — Student ID 62011114
	Mr. Natthakan Manatsa — Student ID 62011165
	Ms. Pawiga Sihawong — Student ID 62011196
Degree	Bachelor of Engineering
Department	Civil Engineering
Advisor	Asst.Prof.Dr.Chodchanok Attaphong

Special project examination committee	Signature
Asst. Prof. Dr. Chodchanok Attaphong	
Assoc. Prof. Dr. Salisa Chaiyaput	
Asst. Prof. Dr. Prateep Lueprasert	
Assoc. Prof .Dr. Preeda Chaturabong	

Accredited by the Department of Civil Engineering

(Associate Professor Dr.Chalida U-tapao)

Head of Department of Civil Engineering

Date...

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Ms. Emwika	Piamsuk	62011114
Mr. Natthakan	Manatsa	62011165
Ms. Pawiga	Sihawong	62011196

Advisor: Asst.Prof.Dr. Chodchanok Attaphong

Academic Year 2022

ABSTRACT

Nowadays, plastic waste is becoming an increasingly serious problem. Because many people use single-use plastic, some plastics were used for a short period of time and they have been disposed of and contaminated the environment. This study is expected to reduce the amount of plastic waste by recycling plastic into a mixture of lightweight bricks by using two types of plastics which are polypropylene (PP) and polyethylene terephthalate (PET). The research results were found that the type and ratio of plastic that is suitable to produce lightweight brick to replace fine aggregate is polypropylene (PP) in the proportion of 20 (m/m) %. The lightweight brick with this 20% of PP had comparable performance to the Thai Industrial Standard (TIS) no. 2601 – 2556. The highest compressive strength of 18.227 kg/cm^2 was close to the standard of C6 lightweight brick with a compressive strength of 20.4 kg/cm^2 and the minimum absorption rate of 15.173%, which was not more than 20% according to the lowest water absorption rate in the Thai Industrial Standard (TIS) no. 2601 – 2556. However, the lightweight brick using PET replacement was not able to be tested because it did not form with a cement mixture. The results from this study will be beneficial in reducing plastic waste and increasing alternatives in the production of lightweight bricks.

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Emwika Piamsuk

Natthakan Manatsa

Pawiga Sihawong

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Chapter 1

Introduction

1.1 Problem significance

Plastic is a packaging that helps people's convenience because it's easy to use. However, these plastics are difficult to decompose and become environmentally waste. There is a problem of plastic waste in Thailand that getting heavier. The information from the Ministry of Natural Resources and Environment (MNRE) in the last ten years (2009-2018). Total solid waste increased from 24.11 million tons to 27.93 million tons, and the amount of plastic waste is increasing every year. In 2018, 12% of solid waste, or about 2 million tons was plastic bags, plastic containers, and bottles. (The Government Public Relations Department, 2021). These plastics have a very short lifespan but take a long time to decompose, and improper handling of plastic waste affects organisms and the environment. This is a problem related to organisms and livelihood that requires urgent attention and solution.

Due to the increasing amount of plastic waste each year, this project can help recycle plastic waste and use it for the benefit of Civil materials. These plastic wastes can be used as fine aggregates, which are a mixture in the production of lightweight brick. In this study, the differences in the properties of lightweight brick and lightweight brick containing Polypropylene (PP) and Polyethylene Terephthalate (PET) plastics.

1.2 Objectives

1.2.1 To investigate the proper ratio of plastic waste as fine aggregates in a lightweight brick.

1.2.2 To determine the physical and chemical properties of lightweight bricks using plastic waste.

1.3 Expected benefits

1.3.1 Reduce the amount of plastic waste that into landfills and may contaminate the environment.

1.3.2 Recycling the plastic wastes for construction material.

1.3.3 Be an alternative admixture for the production process of lightweight bricks.

1.4 Area of study

1.4.1 Study the properties and production process of lightweight brick to compare with the Thai Industrial Standards (TIS).

1.4.2 Study the properties of lightweight bricks, which use Polypropylene (PP) and Polyethylene Terephthalate (PET) as fine aggregates in each ratio.

1.4.3 Study the difference in properties between the lightweight brick and lightweight brick with the plastic waste mixture.

Chapter 2

Literature Reviews

2.1 Lightweight brick

2.1.1 Definition

Lightweight brick is concrete with lower density when compared to conventional concrete. Conventional lightweight brick used nowadays has a density of approximately 2,200 – 2,600 kilograms per cubic meter. Lightweight Brick could be produced by the insertion or substitution of lower-density materials, or the substitution of some parts of lightweight brick by air bubbles (Sukhontasookkul,2012). Lightweight Concrete is a construction material that was developed from block bricks. The development focused on optimization of all-around usage and strengthening the brick for more durability. The main materials used are fine sand, cement, foam, and water.

2.1.2 Manufacturing of lightweight brick

Different lightweight brick's raw materials and manufacturing processes will also result in different properties. Lightweight bricks are categorized into 2 types according to the manufacturing process as follows: (Chaipanich and Chindaprasirt, 2015)

1) Non-Autoclaved system is categorized into 2 types, which are:

Type 1: Using the lighter-weight material as a substitute. Clay is mixed with natural ingredients such as vetiver, sawdust, ash, coconut pulp, rice husk ash, bagasse, foam beads, etc. When the mixtures are burned, they would decompose and become cavities in the brick, making the brick lighter. However, the service life is shorter, and the deterioration rate is faster. Furthermore, in case of fire, the burned fumes are toxic to the residents. It is used in the structure as a heat insulator or wall decoration.

Type 2: Mixing the chemical (Circular Lightweight Brick, CLC) to make the brick expand. The chemical will react with cement and cause air bubbles in the material, then leave it to set. This type of brick shrinks more and causes the plaster to easily crack and not be strong. Most non-autoclaved bricks have a cement color, which is different from white crystallized autoclaved aerated concretes.

2) Autoclaved Aerated Concrete (AAC) is categorized into 2 types based on the raw material used.

Type 1: Lime Base. Lime, which quality control is difficult, is used as the main material. The concrete's quality is unstable with more water absorbed.

Type 2: Cement Base. Type 1 Portland cement is used as the main material. This type produces a constant-quality concrete with a Calcium Silicate formed in the concrete. Thus, concrete is stronger and more durable when compared to other processes.

2.1.3 Thai Industrial Standard (TIS) no. 2601 – 2556

Thai Industrial Standard (TIS) no. 2601-2556 specifies details of air-filled lightweight brick for building lightweight concrete walls with evenly distributed air bubbles in the concrete. Air bubbles are formed by the use of foaming agents. Which specifies the quality class, type, size and criteria of tolerance, and required characteristics. (Thai Industrial Standard no. 2601 – 2556, 2013)

2.1.3.1 Types of lightweight bricks: Lightweight bricks are classified according to dry density, and divided into 8 types, they are C6 to C16 as Table 2.1.

Table 2.1 Types of lightweight brick (Thai Industrial Standard no. 2601 – 2556, 2013)

Type	Dry Density (kg/m^3)
C6	501 – 600
C7	601 – 700
C8	701 – 800
C9	801 – 900
C10	901 – 1000
C12	1001 – 1200
C14	1201 – 1400
C16	1401 – 1600

2.1.3.2 Size and criteria for tolerances: The size of the lightweight brick must be in accordance with Table 2.2. The tolerance of height does not exceed ± 4 mm, the tolerance of length does not exceed ± 5 mm, and the tolerance of thickness does not exceed ± 3 mm as Table 2.2.

Table 2.2 Size and criteria for tolerances (Thai Industrial Standard no. 2601 – 2556, 2013)

Height (mm)	Length (mm)	Thickness (mm)
200	300 400 500 600	As identified on the label

2.1.3.3 Required characteristics

1) General characteristics: No cracking, no distortion, no bending, and no defect that are harmful to use.

2) Volumetric density: Lightweight bricks must have an average volumetric density according to Table 2.1. Each lightweight brick will be different from the specified one that not is more than ± 50 kg/m^3.

3) Compressive strength: Lightweight bricks must have compressive strength according to Table 2.3.

Table 2.3 Compressive strength of lightweight brick (Thai Industrial Standard no. 2601 – 2556, 2013)

Type	Compressive strength not less than MPa (kg/cm^2)
C6	2.0 (20.4)
C7	
C8	
C9	25 (25.5)
C10	
C12	
C14	5.0 (51.0)
C16	

4) Absorption rate: Lightweight bricks must have an absorption rate in accordance with Table 2.4.

Table 2.4 Absorption rate of lightweight brick (Thai Industrial Standard no. 2601 – 2556, 2013)

Type	Absorption rate not greater than (%)
C6	25
C7	
C8	
C9	23
C10	
C12	
C14	20
C16	

2.2 Plastic

Plastics are man-made substances. It is produced by using natural ingredients such as petroleum oil, natural gas, coal, oil, and plant fibers. There are many different types of plastics, and it varies depending on what is being produced and how it is being produced. Some types of plastics can be stiff, some are soft, and others viscous liquids. Plastics that have not been mixed with other substances are known as resins. Resins are mostly transparent and colorless, but some can be opaque. Pure resins are not commonly used to mix with plastics for molding, because using other materials and chemicals in the mix can enhance the quality of the product, such as making the plastic softer or increasing heat resistance. Plastics are designed to meet a wide range of applications. In modern days, large amounts of plastics are being used. Therefore, campaigns are being created to encourage the recycling and reusing of waste materials to protect the environment. The common types of plastics being used nowadays can be categorized as follows. (National Metal and Materials Technology Center, 2022)

2.2.1 Types of plastic

1) Polyethylene Terephthalate (PET) is a transparent, strong plastic with good impact resistance, not brittle, and is gas permeable. It is used for water bottles,

vegetable oil bottles, etc. It can be recycled into fibers used in sweaters, rugs, and synthetic fibers used for pillow stuffing.

2) High-Density Polyethylene (HDPE) is a tough, hard-to-break plastic, resistant to chemicals, acids, and alkalis. It can be easily molded into various shapes and can be recycled into bottles for storing engine oil, plastic pipe, artificial wood, or plastic bags.

3) Polyvinylchloride (PVC) is a durable, chemical-resistant plastic used for water pipes, clear rubber hoses, food wraps, plastic sheets for constructing doors, windows, artificial leather, etc. It can be recycled into water pipes or gutters for agriculture, traffic cones, furniture, plastic benches, tape cassettes, cables, and synthetic wood boards.

4) Low-Density Polyethylene (LDPE) is a tough, flexible, transparent, non-heat-resistant plastic used to make food wraps and wrapping films, bread bags, and cooler bags for food packaging. It can be recycled into black garbage bags, plastic bags, trash bins, and floor tiles.

5) Polypropylene (PP) is a transparent and highly flexible plastic that is heat, chemical, and oil resistant. It is used to make food containers such as boxes, bowls, plates, buckets, baskets, and chilled water bottles. It can be recycled into car battery boxes, auto parts such as bumpers and taillights, plastic brooms, brushes, or compost bins.

6) Polystyrene (PS) is transparent but brittle and easy to break the plastic. It is used to make various containers for storage or foam take-out containers. It can be recycled into clothes hangers, video storage boxes, rulers, bulbs, thermometers, light switchboards, heat insulators, or egg trays.

7) Other types of plastics are a product of many types of plastics, not the 6 types of plastics mentioned above. It can be remelted and recycled into pipes, nuts, wheels, and pallets. (Mahatanee Industrial Company Limited, 2022)

Table 2.5 below summarizes the properties of the 7 types of plastics, divided by their symbols, characteristics, usage, and how they could be recycled.

Table 2.5 Properties of plastics (Mahatanee Industrial Company Limited, 2022)

Full Form	Symbol	Characteristic	Usage	Application after recycling
1. Polyethylene Terephthalate	PET	- Transparent - Impact resistant - Tough, not brittle - Gas permeable	- Drinking water bottles - Vegetable oil bottles	Made into fibers for making sweaters, rugs, and synthetic fibers in pillows.
2. High-Density Polyethylene	HDPE	- High density - Tough, chemicals, acids, and alkalis resistant - Can be easily molded into various shapes	- Milk bottles - Shampoo bottles - Laundry detergent bottles - Chemical containers	Made into containers such as oil tanks, engine oil bottles, laundry detergent bottles, and artificial wood.
3. Polyvinylchloride	PVC	- Durable - Chemical and water resistant	- PVC pipe, bathroom curtain - Clear rubber hose	Made into plumbing pipes, sockets, traffic cones, and benches.
4. Low-Density Polyethylene	LDPE	- Translucent - Flexible - Non-heat resistant	- Plastic bags - Straws - Food wraps	Made into trash bags, plastic bags, floor tiles, and film sheets.

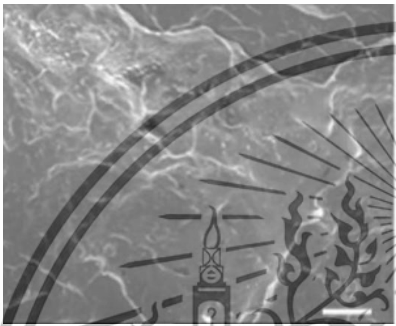
Table 2.5 Properties of plastics (Mahatanee Industrial Company Limited, 2022)

Full Form	Symbol	Characteristic	Usage	Application after recycling
5. Polypropylene	PP	- Transparent - Lightweight - Heat, chemicals, and impact resistant	- Containers such as plates, bowls, hot food bags, water glasses, microwavable, and food containers	Made into a multipurpose container, compost bins, battery box, brush, and plastic broom.
6. Polystyrene	PS	- Transparent, glossy plastic - Brittle - Acid and alkali resistant	- Plastic utensils - Foam containers - Coffee cup - Electrical equipment	Made into a clothes hanger, heat-insulating switch panel, and picture frame.
7. Other types of plastic	Other	- Many types of plastics combined - Heat, acid, and impact resistant	- Pens - Baby feeding bottles, - Safety helmets - Traffic lights	Can be combined with other types of plastics to make pipes, nuts, wheels, and pallets.

2.2.2 Scanning Electron Microscope (SEM) of PP and PET

A type of electron microscope, designed for directly studying the surfaces of solid objects, that utilizes a beam of focused electrons of relatively low energy as an electron probe that is scanned in a regular manner over the specimen. The electron source and electromagnetic lenses that generate and focus the beam are similar to those described for the transmission electron microscope (TEM). The action of the electron beam stimulates the emission of high-energy backscattered electrons and low-energy secondary electrons from the surface of the specimen. For Scanning Electron Microscope (SEM) of PP (Ramasamy, Yang and Rafailovich, 2014) and PET (Arahman,et al., 2017) as Table 2.6.

Table 2.6 Scanning Electron Microscope (SEM) of PP and PET

Surface	Type of Plastics
	Polypropylene
	Polyethylene Terephthalate

Polypropylene (PP) has a property that water can flow through, causing the cement to stick to the plastic. As for Polyethylene Terephthalate (PET), it has properties that prevent flowing through, making the cement not stick together. Similar to plastic coloring that PP can be dyed, PET cannot be dyed. (Mahatanee Industrial Company Limited, 2022)

2.2.3 Size of plastic

Since we use plastic to replace of fine aggregate. Therefore, we use plastic size according to the size of the sand which is a fine aggregate. Sand is one of the important materials that increase strength and it is an insert of concrete, so the different sizes of fine aggregate can affect the strength of lightweight bricks. The size of the fine aggregate must be in accordance with Table 2.7.

Table 2.7 Sizes of coarse aggregate and fine aggregate (Gilson Company, Inc., 2023)

ASTM E11 Test Sieves		
	Standard	U.S. Alternative
Coarse Aggregate	100.0 mm	4 in
	90.0 mm	3-1/2 in
	75.0 mm	3 in
	63.0 mm	2-1/2 in
	50.0 mm	2 in
	37.5 mm	1-1/2 in
	25.0 mm	1 in
	19.0 mm	3/4 in
	12.5 mm	1/2 in
	9.5 mm	3/8 in
	4.75 mm	No. 4
Fine Aggregate	2.36 mm	No.8
	1.18 mm	No.16
	600 μm	No.30
	300 μm	No.50
	150 μm	No.100
	75 μm	No.200

2.3 The plastic waste problem in Thailand

When a large amount of plastic is used, this results in a large amount of plastic being discarded, known as "plastic waste". Plastic is a non-biodegradable material because plastic is a synthetic substance. Polypropylene (PP) and Polyethylene Terephthalate (PET) plastic are considered the largest amount of waste in Thailand.

In the past 10 years between 2009 and 2018, the total amount of solid waste increased from 24.11 million tons to 27.93 million tons and the amount of plastic waste has increased every year. In 2018, plastic waste accounted for 12% of solid waste, or about 2 million tons. which 1.2 million tons are plastic bags and the rest are other types of plastic such as food containers, bottles, and trays. (The Government Public Relations Department, 2022) The situation of plastic waste is even more serious. In 2019, there were 3.45 million tons of plastic waste, in 2020 there was 3.23 plastic waste, and in 2021 was between January and April. with 1.15 million tons of plastic. (Pollution Control Department, 2021) The information shows a growing trend in plastic waste each year. If these wastes are not handled properly, they can affect organisms and the environment.

2.4 Plastic waste disposal

2.4.1 Plastic waste disposal in Thailand

1) Landfill, contaminated plastic waste, not suitable for storage and cleaning, such as plastic bags made of PP (Polypropylene), HDPE (High-Density Polyethylene), and LDPE (Low-density polyethylene), such as hot and cold bags used as food packaging, plastic bags. These wastes are disposed of in landfills or dumped at the dumpsites for disposal of solid waste arranged by a local government organization. This will become a problem for solid waste.

2) Reusing, the process of recycling and reusing is the most beneficial alternative for the environment, in terms of solving plastic waste issues. Recycling plastic products is a complicated and costly procedure as most of them are contaminated. Nowadays, only a fraction of plastic bags is returned to factories for recycling. As a result, a large amount of discarded plastic bags become solid waste and remain in the environment.

3) RDF (Refuse Derived Fuel), turning plastic waste into RDF is an exceptional way to manage plastic waste because it provides high heating value, suitable for use as RDF by refining and converting plastic waste into fuel. In Thailand, RDF is used as fuel in major cement plants such as the Siam Cement Company (SCC), Siam City Cement Company (SCCC), and TPI Cement Company.

4) Incineration, unsorted plastic waste is usually disposed of as general solid waste. Thailand has two types of incineration systems, namely WTE (Waste to Energy) incinerators, and waste incinerators. There are only 6 incinerators that generate energy, 37 are incinerators that follow correct procedures, while 57 of them are

incinerators that do not comply with correct procedures. Improper waste incineration will result in pollutants in the atmosphere, which may lead to the contamination of soil and water.

5) Oil, plastic waste can be converted into Pyrolysis oil because plastic waste contains hydrocarbons as the main element. Thailand has conducted an experimental study on converting plastic waste into pyrolysis oil in many areas, but none has shown significant results (Pollution Control Department, 2020).

2.4.2 Roadmap

From the summary of Thailand's plastic waste cycle chart, the property of plastic includes flexibility, enabling it to be molded into a variety of products. Therefore, plastics are increasingly being used to replace many products. As a result, in the past 10 years (between 2009-2018), Thailand accounted for approximately 12 percent of the total amount of plastic waste generated or about 2 million tons per year. An average of about 0.5 million tons per year were being reused, while the remaining 1.5 million tons, most of which are single-use plastics such as hot and cold food bags, plastic bags, cups, straws, and food packaging foam boxes were not reused in the circular economy. This results in a waste of budget and plastic landfill space.

Recognizing the importance and being aware of the environmental pollution problem caused by plastic waste, the government of Thailand has established a Subcommittee on Plastic Waste Management under the National Environment Board. They prepared Thailand's Roadmap on Plastic Waste Management 2018 - 2030 to serve as a framework and direction for preventing and solving plastic waste management in Thailand. The objective of the roadmap is in line with the 14th Sustainable Development Goal to conserve and sustainably use the oceans, seas, and marine resources. It consists of two sub-targets. Firstly, it is to reduce and replace the use of some single-use plastic by using environmentally friendly materials. In other words, it is to stop using three types of plastic, namely, cap seals, Oxo degradable plastic, and plastic microbeads by 2019. And in 2022, they would stop using 4 more types of plastics, including plastic bags, foam food containers, thin plastic cups, and plastic straws. Secondly, the goal is to recycle 100 percent of target plastic wastes by 2027, with studies, setting objectives in recycling plastics, and disposing of plastic waste appropriately, which is to manage plastic waste by incinerating it as energy. Similarly, this research aligns with the country's roadmap to reduce the amount of plastic waste, such as plastic bottles and hot bags (Legislative Institutional Repository of Thailand, 2019). Thailand’s plastic waste cycle according to Figure 2.1.

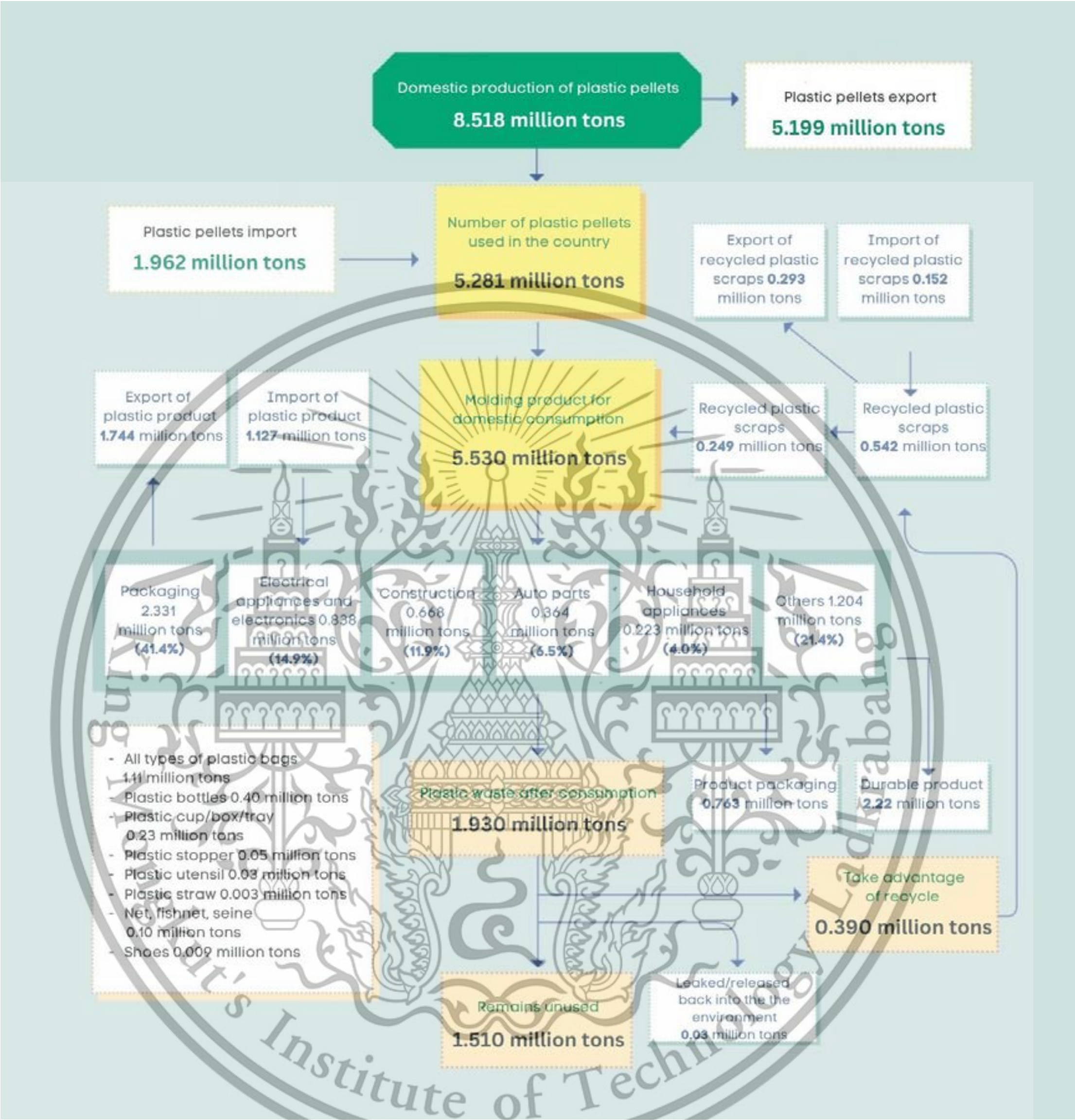


Figure 2.1 Thailand’s plastic waste cycle (Pollution Control Department, 2020)

2.5 Analysis

From studies and literature review, this research focuses on the properties of lightweight brick. The important properties of lightweight bricks are lightweight materials, fire resistance, easily cut into shapes which reduced construction time, and soundproofing. After studying the properties of various types of plastics, it was found that Polypropylene (PP) and Polyethylene Terephthalate (PET) plastics are suitable to be used as fine aggregates in the production of lightweight bricks. The properties of these plastics are lightweight, able to impact resistance, not easily deformed, high heat resistance, and moisture-proof. Including they are types of plastic that meet the widespread and common comfort of use. Also, they are types of plastic that account for a large proportion of the total amount of plastic waste. Planning of the study, which divided into 3 main parts as follows.

1) Study the properties and production process of lightweight brick to compare with the Thai Industrial Standards (TIS).

2) Study the properties of lightweight bricks, which use Polypropylene (PP) and Polyethylene Terephthalate (PET) plastics as fine aggregates in each ratio.

3) Study the difference in properties between the lightweight brick and lightweight brick with the plastic waste mixture.

Chapter 3

Methodology

This research study is experimental research to study the difference in the properties of lightweight brick and lightweight brick containing plastic waste as fine aggregates. This research collected information on topics related to lightweight brick, types of plastic, and the Thai Industrial Standard (TIS) of Cellular Lightweight Concrete (CLC).

3.1 Methodology diagram

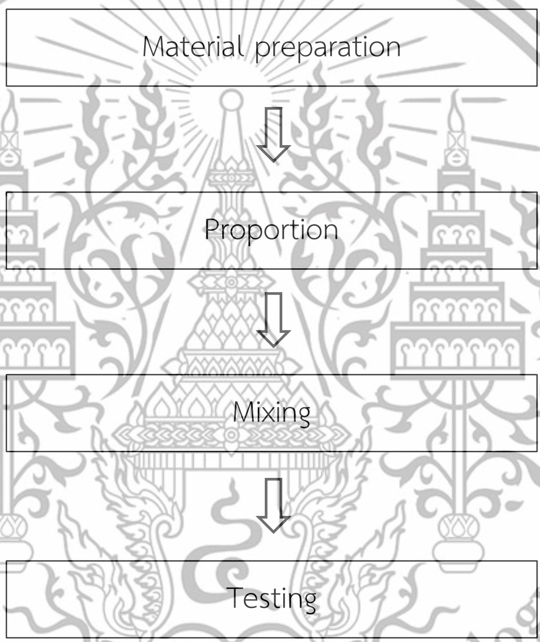


Figure 3.1 Methodology diagram

The research plan is divided into 4 steps, consisting as follows. Firstly, material preparation is the preparation of raw materials and equipment for making CLC. Secondly, the proportion is the ratio of doing CLC divided into the ratio for mixing raw materials and the calculation of various raw materials for mixing. Thirdly, mixing is bringing various raw materials together according to the ratio that is available. Lastly, testing the CLC to find out the desired values, namely Volumetric density, compressive strength, and absorption rate.

3.2 Materials and equipment

Materials

1) Type I – normal Portland Cement

2) Fine sand

3) Polypropylene (PP) and Polyethylene Terephthalate (PET) plastics

4) Water

5) CLC Foaming Agent

Equipment

1) Cement mixer tub

2) Hoe

3) Scale

4) Lightweight concrete formwork

5) Drill

6) Universal Testing Machine (UTM)

7) Oven

8) Vernier

3.3 Quantity of materials required

The amount of material used was determined according to the required density of lightweight bricks, 1000 kg/m^3, with the ratio of cement to sand being 1:2 and water to cement being 0.58. There were 5 experiments. About the production of lightweight bricks using plastic waste. (Change the ratio of sand to plastic waste). Determine the ratio for mixing lightweight concrete (CLC) according to Table 3.1 and the total amount of materials for the production process both lightweight brick and lightweight brick containing plastic waste according to Table 3.2. (Chapirom, 2014)

Table 3.1 The ratio for mixing of CLC

Type	Type I – normal Portland Cement: Sand	Water: Type I – normal Portland Cement	CLC Foaming Agent: Water	Change the ratio of sand to plastic waste
Conventional Brick	1 : 2	0.58	1 : 40	50 : 0
Experiment 1	1 : 2	0.58	1 : 40	40 : 10
Experiment 2	1 : 2	0.58	1 : 40	30 : 20
Experiment 3	1 : 2	0.58	1 : 40	20 : 30
Experiment 4	1 : 2	0.58	1 : 40	10 : 40
Experiment 5	1 : 2	0.58	1 : 40	0 : 50

Table 3.2 Summary of calculation of the mixture of CLC

Type	Type I – normal Portland Cement (kg)	Sand (kg)	Water (liters)	CLC Foaming Agent (liters)	plastic waste (kg)
Conventional Brick	1.423	2.8460	0.606	0.0055	0
Experiment 1	1.423	2.2768	0.606	0.0055	0.5692
Experiment 2	1.423	1.7076	0.606	0.0055	1.1384
Experiment 3	1.423	1.1384	0.606	0.0055	1.7076
Experiment 4	1.423	0.5692	0.606	0.0055	2.2768
Experiment 5	1.423	0	0.606	0.0055	2.8460
Summary	8.538	8.5380	3.636	0.033	8.5380

3.4 Production process of conventional lightweight brick

1) Prepare clean water to mix with cellular lightweight concrete admixture in a bucket of water and stir slowly until the solution is completely dissolved.

2) Prepare of air bubbles since the air bubble foam machine is broken, it uses the method of spinning to froth instead. Using a motor to spin until the desired amount of foam is formed.

3) Grind the sand with a grinder and ground it by mixing it with water.

4) Prepare fresh concrete, prepare lightweight brick mix from the "Lightweight brick mix ratio" and then mix with mortar or cement-sand according to the ratio.

5) Mix slowly adding the air bubble foam obtained from step 3.3.2 to the fresh concrete obtained from step 4 and mixes the fresh concrete with the air bubble foam.

6) Pour the mixed material into the mold that size which is 15 cm x 15 cm x 15 cm.

7) Remove the lightweight brick form should allow them to harden for at least 24 hours before it can be removed.

8) Cure lightweight brick for a density of 1000 kg/m^3 or higher that should be cured with moisture for at least 3 days by spraying water or covering it with moist materials.

9) Check the quality of lightweight brick.

3.5 Production process of the lightweight brick using plastic waste

1) Bring plastic waste into the plastic shredder to a size of 0.5 mm - 1.5 mm to replace the fine aggregates.

2) Mix materials according to the ratio by specifying 1 portion from the "Lightweight brick mix ratio".

3) Mix the ingredients according to the original ratio, only changing the ratio of sand to plastic according to the experiments for all 5 types is 40:10, 30:20, 20:30, 10:40, and 0:50.

4) Pour the mixed material into the mold that size which is 15 cm x 15 cm x 15 cm.

5) Remove the lightweight brick form should allow them to harden for at least 24 hours before it can be removed.

6) Cure lightweight concrete for a density of 1000 kg/m^3 or higher that should be cured with moisture for at least 3 days by spraying water or covering it with moist materials.

7) Check the quality of lightweight brick.

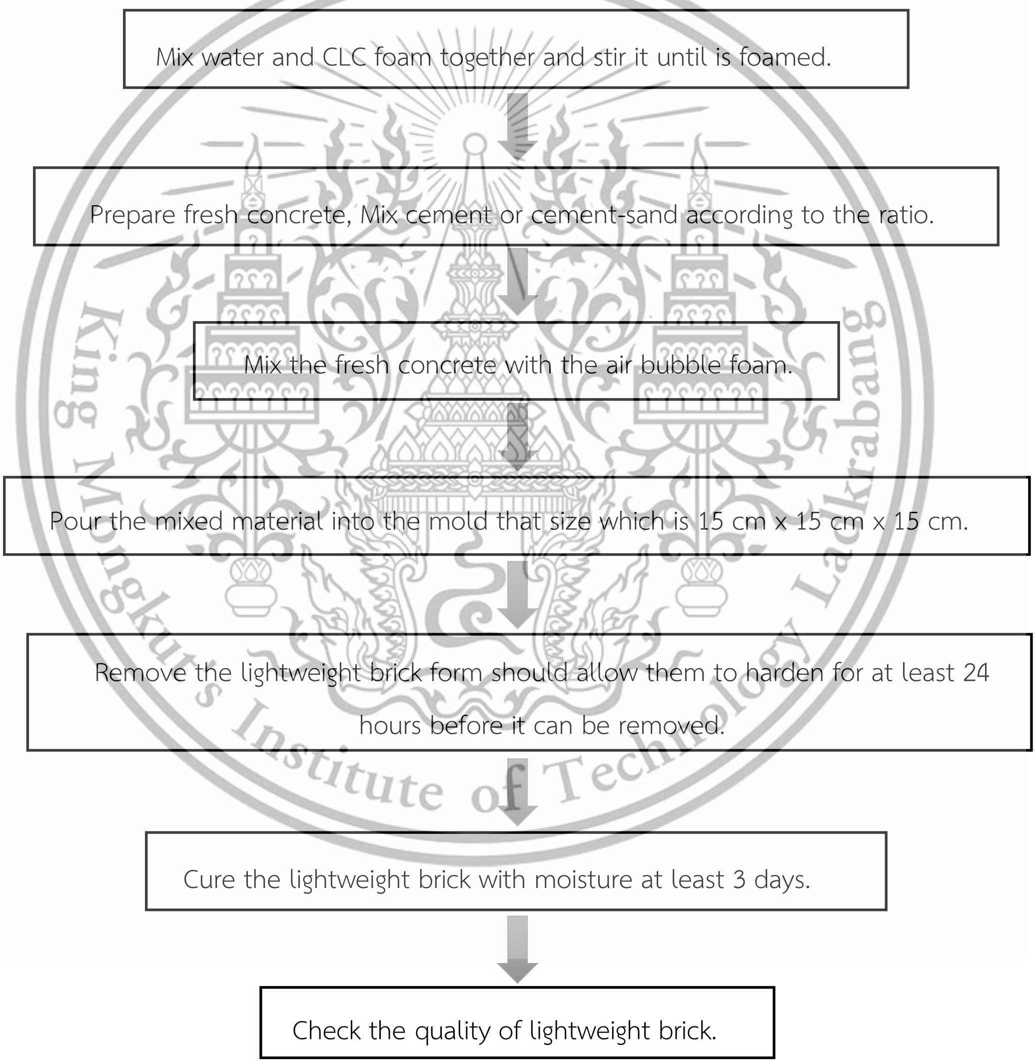


Figure 3.2 Production process of lightweight brick

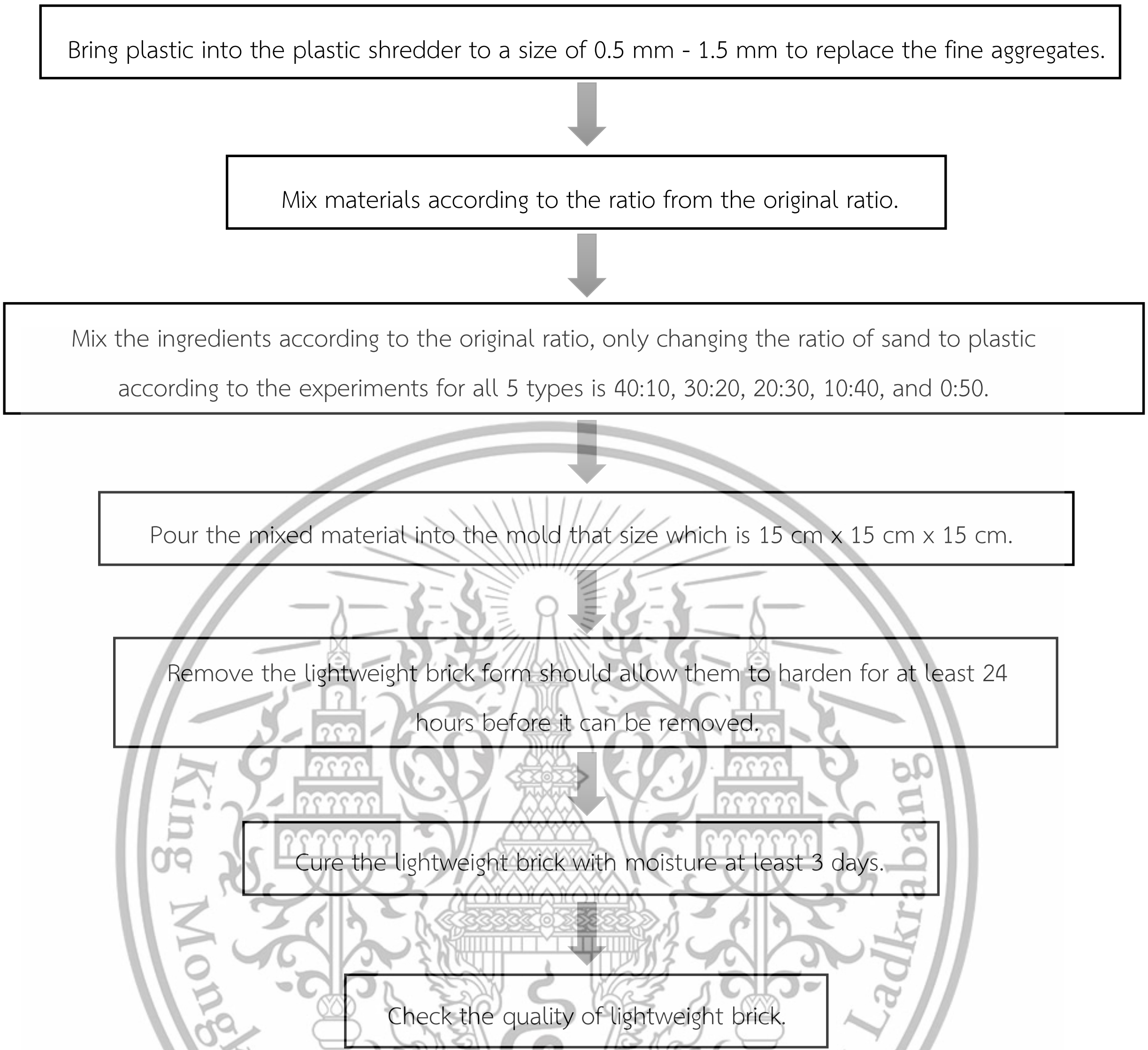


Figure 3.3 Production process of the lightweight brick using plastic waste

3.6 Test for analysis of the properties of lightweight brick

3.6.1 Volumetric density

Volumetric density is the value that indicates the type of lightweight brick. The specimens of lightweight brick size 150 mm x 150 mm x 150 mm, and weigh each of the specimens after they were in an oven for 24 hours at 110±5 ℃. The equation for the calculation of volumetric density is below. (Thai Industrial Standard no. 2601 – 2556, 2013). Lightweight bricks are classified according to dry density according to Table 2.1.

$$\rho = \frac{m}{v}$$

When ρ = Dry density (kg/m^3)

m = Mass of the specimen after oven (kg)

v = Volume of the specimen (m^3)

3.6.2 Compressive strength

The Compressive strength is tested for the maximum load capacity of lightweight bricks until the specimens were broken. The specimens of lightweight brick size 150 mm x 150 mm x 150 mm, at a dry density equal to 1,000 kg/m^3. Then test the specimen with Universal Testing Machine (UTM) until the maximum compressive strength is obtained, which means the specimen is broken. Lightweight bricks must have compressive strength according to Table 2.3.

3.6.3 Absorption rate

The absorption rate is the water absorption capacity of lightweight bricks. The specimens of lightweight brick size 150 mm x 150 mm x 150 mm, and then the specimens into an oven for 24 hours at 110±5 ℃. Allow them to cool at room temperature for not less than 4 hours, then weigh each specimen when they are dry. Then put the specimens in the water for 24 hours and weigh each specimen. The equation for the calculation of the absorption rate is below. (Thai Industrial Standard no. 2601 – 2556, 2013). Lightweight bricks must have an absorption rate in accordance with Table 2.4.

$$A = \frac{m2 - m1}{m1} \times 100$$

When	A	=	Absorption rate (%)
	m1	=	Mass of the specimen when dry (g)
	m2	=	Mass of the specimen when wet (g)

Chapter 4

Results and Discussions

All two parts of the work plan outlined in Chapter 3 have been carried out. The study's findings included the following information: (1) volumetric density of lightweight brick (2) compressive strength of lightweight brick (3) absorption rate of lightweight brick.

Part 1 Testing volumetric density, compressive strength, and water absorption of lightweight brick cubes sample from the conventional ratio. Shown as 4.2, 4.4, and 4.6.

Part 2 Testing volumetric density, compressive strength, and water absorption of lightweight brick cubes sample from the conventional ratio but changing the ratio of sand to plastic according to the experiments for all 5 types is 40:10, 30:20, 20:30, 10:40, and 0:50. shown as 4.8 and 4.12.

A sampling of the lightweight brick using the same weight unit In TIS 2601-2556, the difference in wet weight will not exceed 30 kg/m^3. Lightweight bricks with air inside are regarded as having an average dry bulk density. The subsequent analysis will include the test findings.

4.1 Physical characteristics of lightweight brick

For the conventional lightweight brick and lightweight brick using plastic as fine aggregate in the ratio of sand to cement 2:1 and the water-cement ratio of 0.58, the physical characteristics are as Table 4.1.

Table 4.1 Physical characteristics of lightweight brick

Type	No.1	No.2	No.3
Conventional			

Table 4.1 Physical characteristics of lightweight brick

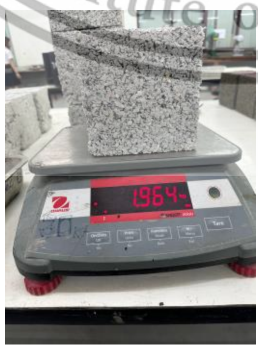
Type	No.1	No.2	No.3
Polypropylene (PP) 20%			
Polypropylene (PP) 40%			
Polypropylene (PP) 60%			
Polypropylene (PP) 80%			

Table 4.1 Physical characteristics of lightweight brick

Type	No.1	No.2	No.3
Polypropylene (PP) 100%			
Polyethylene Terephthalate (PET) 20%			
Polyethylene Terephthalate (PET) 40%, 60%, 80% and 100%			

From Table 4.1, it was found that lightweight bricks replace Polypropylene (PP) as fine aggregates in the ratios of 20% and 40% had the most similar physical characteristics to the conventional brick. While the physical characteristics of Polyethylene Terephthalate (PET) are cracked and not homogeneous. So, it cannot be used to test the volumetric density, compressive strength, and absorption rate. Therefore, in the reporting test results are only Polypropylene (PP) test results that reported.

4.2 Testing volumetric density of the conventional lightweight brick

When preserving lightweight brick samples, allow them to age in water for the required 7 days before testing. To determine the size, take a sample and weigh 3 cubes when dry, using the results to determine the workpiece's density. Each sample cube's dimensions, weight, and density should be noted. Then do the following to determine the value as given in Table 4.2.

Table 4.2 Testing volumetric density of the conventional lightweight brick

No.	Width (cm)	Length (cm)	Height (cm)	Mass (kg)	Density (kg/m^3)
1	15.020	15.138	15.102	4.722	1375
2	15.060	15.118	15.068	4.651	1355
3	15.154	15.176	15.002	4.543	1316

The density of conventional lightweight brick at the age of 7 days is known from Table 4.2 to be the value from the test of 3 samples, which will be used to examine the test findings in the following section.

4.3 Analysis of volumetric density test results of conventional lightweight brick

When utilizing a water-cement ratio of 0.58 and a sand-cement ratio of 2:1 for 3 cubes, the density of lightweight brick aged 7 days at the size of 15*15*15 cm was tested. It is clear from 4.2 that the obtained density falls inside the 1201-1400 kg/m^3 or C14 range. Compared to the criteria according to TIS 2601-2556.

4.4 Testing compressive strength of conventional lightweight brick

When preserving lightweight brick samples by curing in water aged for 7 days, 3 samples were tested for compressive strength at a wet density of 1201-1400 kg/m^3 using a water-cement ratio of 0.58 and a sand-cement ratio of 2:1. The compressive strength of each sample as the values in Table 4.3 as follows.

Table 4.3 Testing compressive strength of conventional lightweight brick

No.	Density (Kg/m^3)	S:C	W/C	Compressive Strength in 7 days (kg/cm^2)
1	1375	2:1	0.58	66.674
2	1355	2:1	0.58	59.318
3	1316	2:1	0.58	52.500

4.5 Analysis of compressive strength test results of conventional lightweight brick

When taking the results from the compressive strength test of lightweight brick aged 7 days at a density of 1201-1400 kg/m^3 using a water-cement ratio of 0.58 and a sand-cement ratio of 2:1 for 3 cubes from data Table 4.3 can be used to graph the relationship between compressive strength and density values as shown in Figure 4.1.

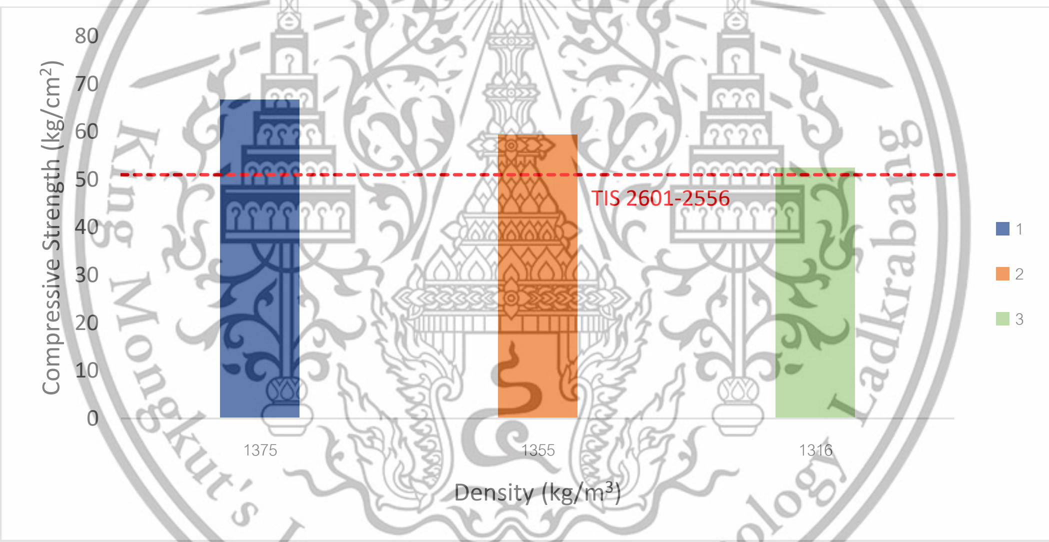


Figure 4.1 Shows the 7-day relationship between the conventional lightweight brick's compressive strength and density

Figure 4.1 shows the relationship between compressive strength and density of lightweight brick 1201-1400 kg/m^3 (C14) and found that in the ratio of sand to cement 2:1 and the water-cement ratio 0.58, the compressive strength is between 52.50-66.67 kg/cm^2. The red dashed line shown in the figure represents the Thai Industrial Standard (TIS 2601-2556). And the lightweight brick for C14 that passes the standard must have compressive strength higher than the dashed line or higher than 51.0 kg/cm^2. From the figure, it was shown the ratio according to the conventional ratio was tested, and the results were in accordance with the specified measures, namely the density in the range of 1201-1400 kg/m^3 or C14.

4.6 Testing absorption rate of conventional lightweight brick

When preserving lightweight brick samples by curing in water aged for 7 days, 3 samples were tested for absorption rate at a wet density of 1201-1400 kg/m^3 using a water-cement ratio of 0.58 and a sand-cement ratio of 2:1. The absorption rate of each sample as the values in Table 4.4 as follows.

Table 4.4 Testing absorption rate of conventional lightweight brick

No.	Density (Kg/m^3)	S:C	W/C	Absorption Rate in 7 days (%)
1	1375	2:1	0.58	9.360
2	1355	2:1	0.58	9.374
3	1346	2:1	0.58	9.649

4.7 Analysis of absorption rate test results of conventional lightweight brick

When taking the results from the absorption rate test of lightweight brick aged 7 days at a density of 1201-1400 kg/m^3 using a water-cement ratio of 0.58 and a sand-cement ratio of 2:1 for 3 cubes from data Table 4.4 can be used to graph the relationship between absorption rate and density values as shown in Figure 4.2.

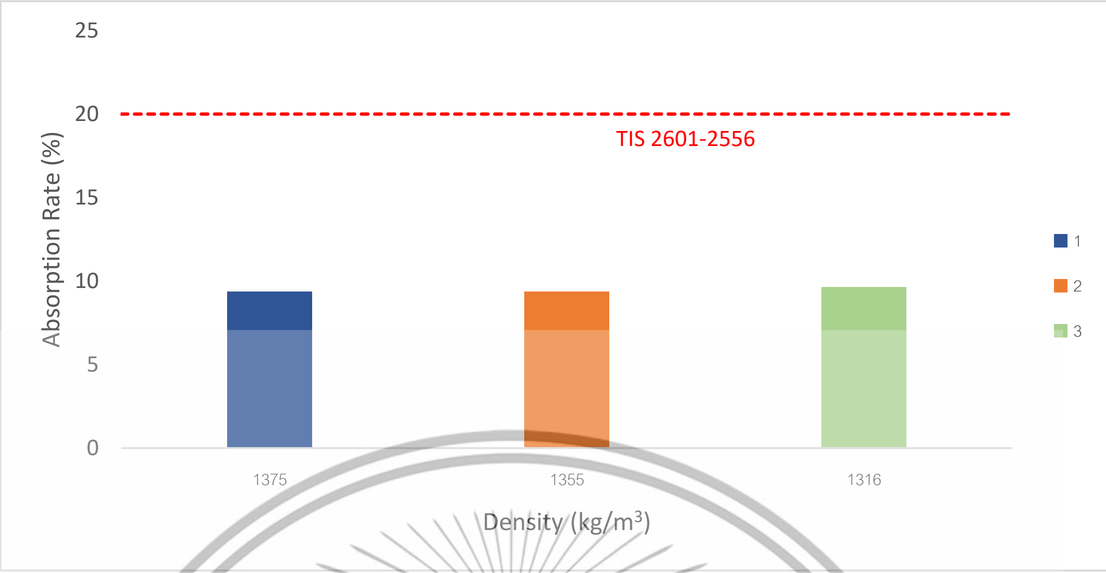


Figure 4.2 Shows the 7-day relationship between the conventional lightweight brick's absorption rate and density

Figure 4.2 shows the relationship between the absorption rate and density of lightweight bricks 1201-1400 kg/m^3 (C14) and found that in the ratio of sand to cement 2:1 and the water-cement ratio 0.58, the absorption rate is between 9.360 – 9.649 %. The red dashed line shown in the figure represents the Thai Industrial Standard (TIS 2601-2556). And the lightweight brick for C14 that passes the standard must have an absorption rate not higher than 20%. From the figure, it can be seen that in the ratio according to the conventional ratio that was tested, the results were in accordance with the specified measures. It was found that the density of 1375 kg/m^3 gave the lowest absorption rate is 9.360% and the density of 1316 kg/m^3 gave the highest water absorption rate is 9.649%.

Lightweight bricks with a density of 1375 kg/m^3 had lower water absorption than the density of 1355 and 1346 kg/m^3, respectively. When the density increases affect the water absorption rate decreases. It is known that water absorption is inversely proportional to the density of lightweight bricks.

4.8 Testing for analysis of the properties of lightweight brick using Polypropylene (PP) as fine aggregates

In this section presents the analysis of density test results, compressive strength test results and water absorption values of lightweight brick of cube-shaped samples, number 15 cubes according to the original ratio but changing the ratio of sand to plastic according to the experiments for all 5 types is 20%, 40%, 60%, 80%, and 100% with the density of 1200-1400 kg/m^3 as shown in Table 4.5.

Table 4.5 Testing for analysis of the properties of lightweight brick using Polypropylene (PP) as fine aggregates

No	PP	Density (kg/m^3)	Compressive Strength (kg/cm^2)	Absorption Rate (%)
1	20%	1061	15.948	15.788
2		1058	17.372	15.836
3		1088	18.227	15.173
4	40%	913	7.458	18.822
5		960	10.534	16.677
6		956	10.164	16.557
7	60%	704	4.709	23.667
8		763	6.005	23.683
9		718	4.887	23.662
10	80%	565	2.467	29.837
11		557	2.308	27.921
12		579	2.660	25.807
13	100%	497	1.958	25.641
14		489	1.915	26.303
15		496	2.085	26.380

From Table 4.5, it shows the values obtained from testing various properties of lightweight bricks that use plastic to replace fine aggregates in the following ratios: 20%, 40%, 60%, 80% and 100% using the water-cement ratio was 0.58 and the sand-cement ratio was 2:1, the results of which will be used to analyze the test results in the next section.

4.9 Analysis of volumetric density test results of lightweight brick using Polypropylene (PP) as fine aggregates

When the lightweight bricks were recorded after being incubated in water for 7 days, it showed that the density values were related to plastic substitutes in fine aggregates. When the amount of plastic increases according to various ratios The density will be reduced significantly.

4.10 Analysis of compressive strength test results of lightweight brick using Polypropylene (PP) as fine aggregates

When taking the results from the compressive strength test of lightweight brick aged at 7 days at a density of 489-1,088 kg/m^3, using a water-cement ratio of 0.58 and a sand-cement ratio of 2:1, and using Polypropylene (PP) substitute in fine aggregates, amount 15 cubes from the data of table 4.5 can be used to graph the relationship between compressive strength and the amount of plastic that can be used is shown in Figure 4.3.

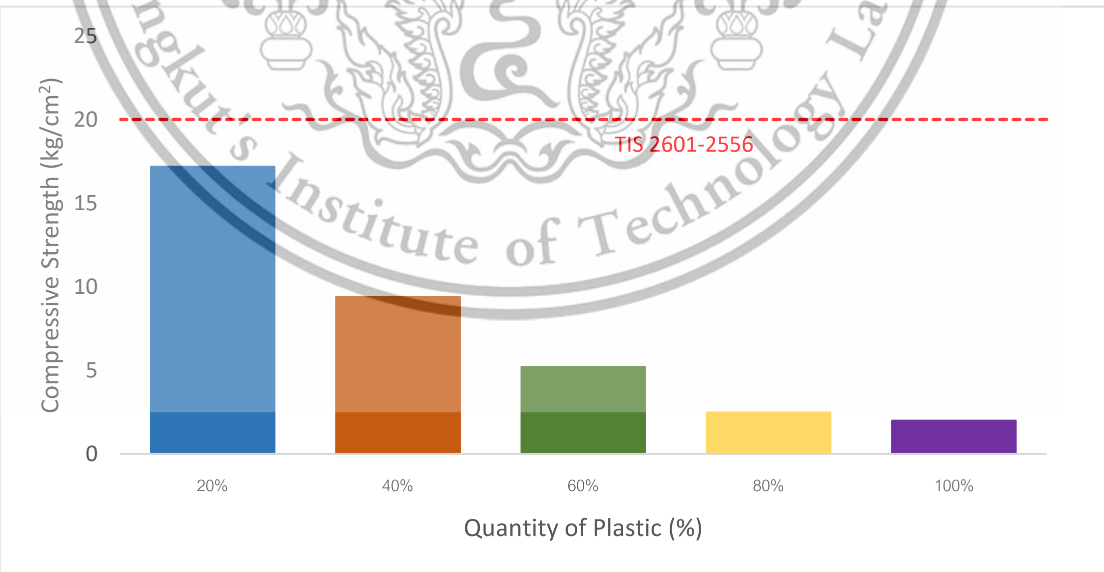


Figure 4.3 The relationship between the lightweight brick's compressive strength and quantity of plastic (%) using plastic PP as fine aggregates

Figure 4.3 shows the results of testing the compressive strength of lightweight brick using plastic Polypropylene (PP) instead of fine aggregate. The plastic ratio was 20%, 40%, 60%, 80%, and 100%, the water-to-cement ratio was 0.58, and the sand-to-cement ratio was 2:1. The results in the above ratio does not meet the standards set (TIS. 2601-2556).

4.11 Analysis of absorption rate test results of lightweight brick when using Polypropylene (PP) as fine aggregates

When taking the results from the absorption rate test of lightweight brick aged at 7 days at a density of 489-1,088 kg/m^3 using a water-cement ratio of 0.58 and a sand-cement ratio of 2:1, and using plastic Polypropylene (PP) substitute in fine aggregates, amount 15 cubes from the data of table 4.5 can be used to graph the relationship between absorption rate and the amount of plastic that can be used is shown in Figure 4.4.

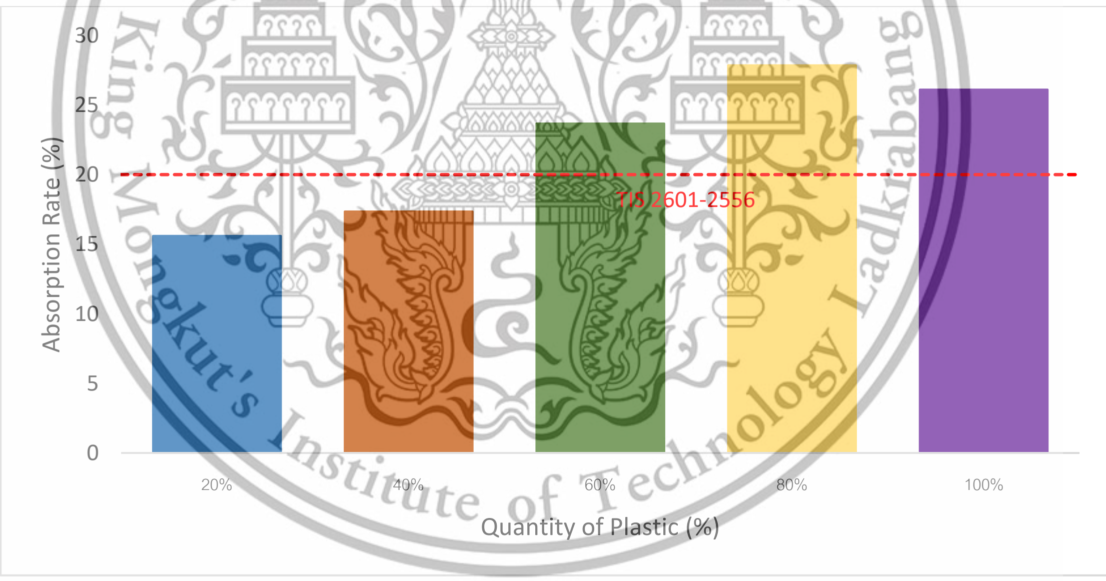


Figure 4.4 Shows the relationship between the lightweight brick's absorption rate and quantity of plastic (%) using plastic PP as fine aggregates

Figure 4.4 shows the results of testing the absorption rate of the lightweight brick using plastic Polypropylene (PP) instead of fine aggregate. The plastic ratio was 20%, 40%, 60%, 80%, and 100%, the water-to-cement ratio was 0.58, and the sand-to-cement ratio was 2:1, the absorption rate is between 15.173-29.837%. There are results in the ratio of 20% and 40% that have a water absorption rate of not more than 20%

which passes the standard set (TIS. 2601-2566). The ratio that 60%, 80%, and 100% have a water absorption rate of more than 20% which does not pass the standard (TIS. 2601-2566).

4.12 Testing for analysis of the properties of lightweight brick using Polyethylene Terephthalate (PET) as fine aggregates

From the experimental observation during the experiment, the results showed that the lightweight brick did not adhere to the Polyethylene Terephthalate (PET) plastic in every ratio, both 20%, 40%, 60%, 80%, and 100% due to the scanning electron microscope (SEM) images of the surface of PP and PET plastics. The surface of PP plastic looks rougher than PET plastic. As a result, PP plastic can bind together with cement better than PET plastic.

4.13 Material Flow Analysis (MFA)

MFA consists of several steps that are described in stages. MFA generally begins with an adequate definition of the problem and goals. The relevant ingredients and scope of the system are then selected. The results are presented in an appropriate way to visualize the conclusion and to facilitate the implementation of goal-oriented decisions. The selections and provisions that are taken during the course of MFA have to be checked continuously. It is best to start with rough estimations and provisional data, and then to constantly.

For 1 conventional lightweight brick, all inputs are cement, sand, foam, and water. And for the quantity of inputs from the mortar which it's from mixing sand and cement is 4.27 kg, the foaming agent and water for foam 0.23 kg, and water 0.61 kg, and finally, the output is 1 lightweight brick weighing 5.1 kg as Figure 4.5. For 1 lightweight brick using PP for 20%, The amount of sand has been reduced and increase the amount of plastic to 20% by using sand 2.28 kg and PP plastic 0.57 kg. The cement, foam and water remain the same as the conventional lightweight brick. And in the end, the output is a lightweight brick with a mixture of PP plastic 20% with a weight of 5.1 kg shows in Table 4.6.

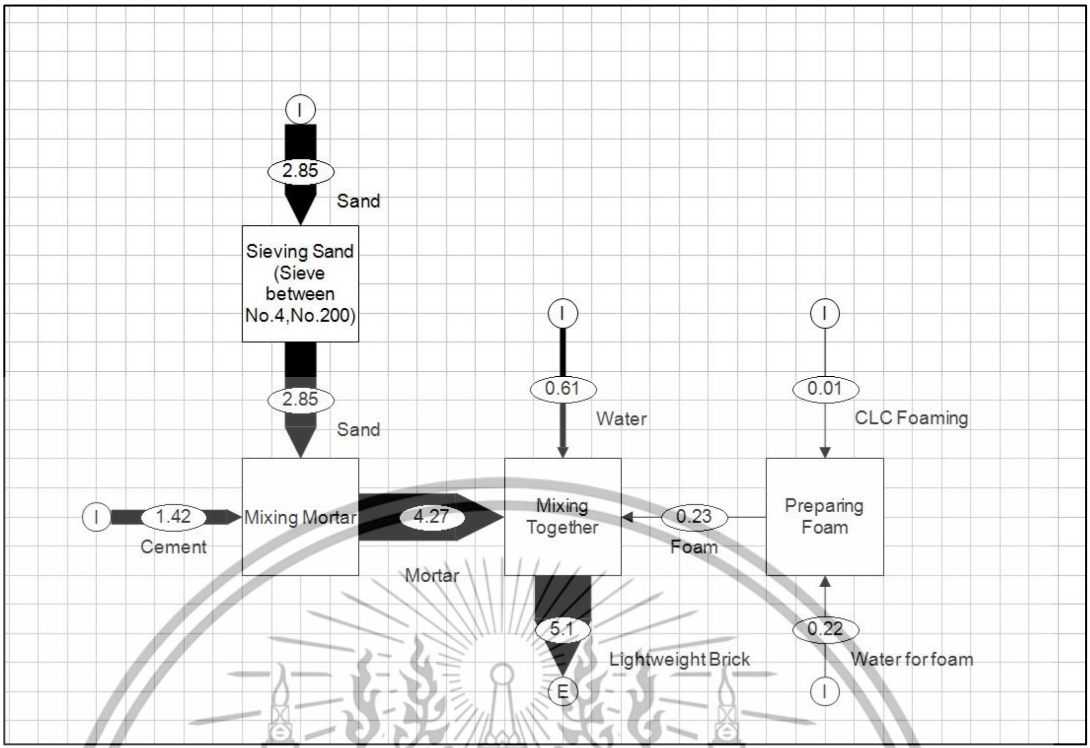


Figure 4.5 MFA of conventional lightweight brick

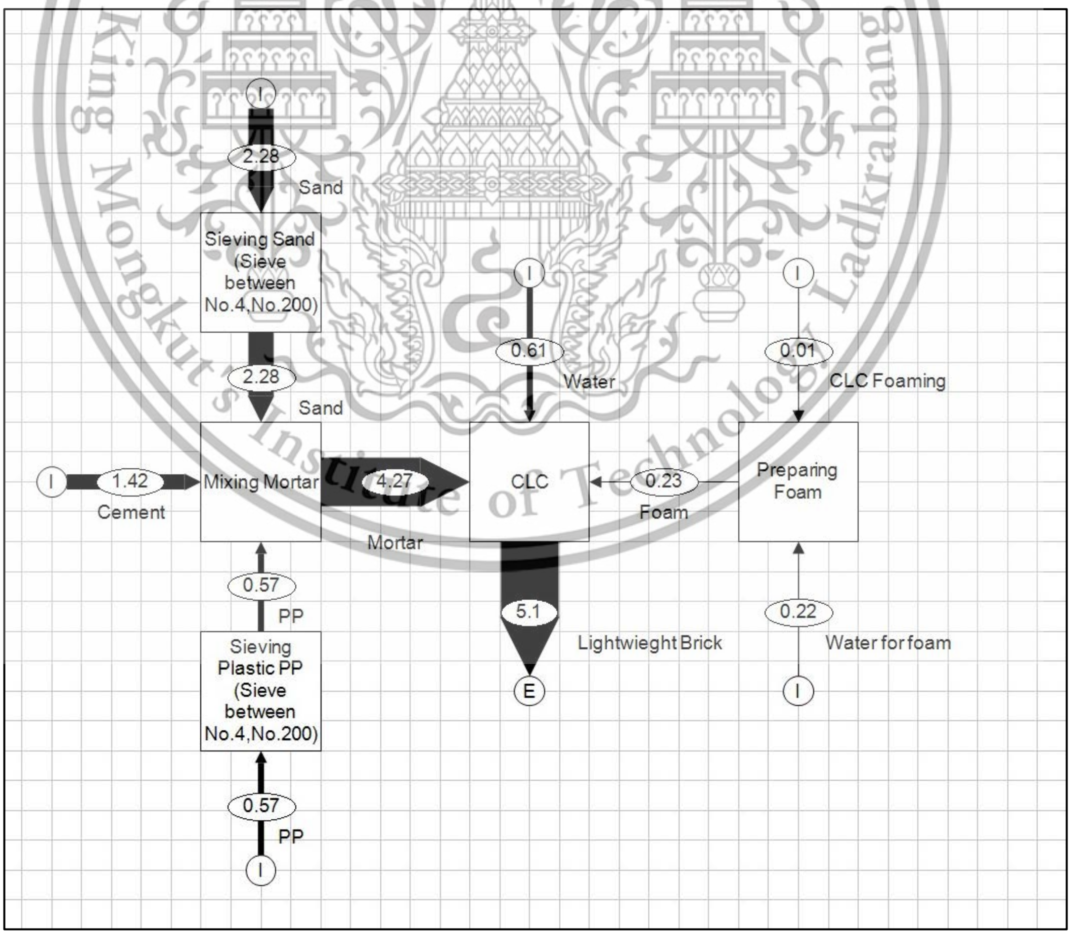


Figure 4.6 MFA of lightweight brick using PP in the proportion of 20%

4.14 Cost estimation

From MFA analysis, material quantity, and unit price are known. Finally, the price of lightweight brick can be calculated. The price of a conventional lightweight brick is 5.486 baht per brick which is calculated as Table 4.6, and a lightweight brick with PP plastic as a fine aggregate of 20% has a price of 5.360 baht per brick which is calculated as Table 4.7. The price of PP plastic in this study is assumed to be 0 baht because it is used to process plastic waste, therefore there is no cost in this section.

Table 4.6 Cost estimation for conventional lightweight brick

No.	Lists	Amount (1 piece)	Units	Unit price	Total (baht)
1	Cement	1.420	Kilogram	2.36	3.35
2	Sand	2.850	Kilogram	0.22	0.63
3	Water	0.830	Liter	0.01	0.01
4	CLC Foaming Agent	0.010	Liter	150	1.50
				Amount per 1 piece	5.49

Table 4.7 Cost estimation for lightweight brick using PP in the proportion of 20%

No.	Lists	Amount (1 piece)	Units	Unit price	Total (baht)
1	Cement	1.420	Kilogram	2.36	3.35
2	Sand	2.280	Kilogram	0.22	0.50
3	PP 20%	0.570	Kilogram	0.00	0.00
4	Water	0.830	Liter	0.01	0.01
5	CLC Foaming Agent	0.010	Liter	150	1.50
				Amount per 1 piece	5.36

Chapter 5

Conclusions and Suggestions

5.1 Conclusions

This research is to study the properties of lightweight bricks replaced with Polypropylene (PP) and Polyethylene Terephthalate (PET) as fine aggregate by studying density, compressive strength, and absorption rate. The experimental results can be summarized as follows.

1. Lightweight bricks containing Polypropylene (PP) replace as fine aggregate in ratios of 20%, 40%, 60%, 80%, and 100%, there is none of the ratios passed the density and compressive strength in accordance with the Thai Industrial Standard (TIS 2601-2556). But Polypropylene (PP) in the ratio of 20% and 40%, the absorption rate has passed the Thai Industrial Standard (TIS 2601-2556).

2. Lightweight bricks containing Polyethylene Terephthalate (PET) replace as fine aggregate in ratios of 20%, 40%, 60%, 80%, and 100%, they cannot be tested for density, compressive strength, and absorption rate. Therefore, Polyethylene Terephthalate (PET) does not have the ability to adhere to cement well enough. As a result, the lightweight bricks do not stick together and crack, so lightweight bricks in all ratios cannot be tested. It can be concluded that none of the ratios can pass the Thai Industrial Standard (TIS 2601-2556).

5.2 Suggestions

From this research, the researcher suggests additional to be a guideline for those who want to continue their research studies as follows.

1. The amount of sand should be prepared for sieving according to the desired ratio. Because if the sand is left for a long time, the sand will become moist and clump to reduce the time spent sifting through the sieve.

2. Morta should not be mixed for more than 10 minutes as it may harden and cannot be mixed with foam.

3. To prepare the foaming agent, it should be blended at the same time with the prepared mortar because spinning the foaming agent for a long time will cause the separation of the foam and cause a large number of air bubbles will result in the lightweight bricks being too porous, which may affect the results of the experiment.

4. The size of fine aggregates should be in the range of 0.075-2.000 mm due to the higher fineness of the material will make it better adhere to the cement.

5. The amount of plastic replacement should be reduced to between 0-20%. Due to the large amount of plastic used, it will reduce the weight of the lightweight brick. As a result, the density and compressive strength values decreased. While the absorption rate increases.

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Author Biography

Name-Surname: Miss Emwika Piamsuk

Date of Birth: 25th August 2000

Address: 38/22 Moo3 Lumlukka Rd.,
Ladsawai, Lumlukka, Pathumthani Province
Zip code. 12150

E-mail: aum.emwk2@gmail.com

Telephone: 088-383-1112

Educational record:

2013 – 2015	Middle school at Sarasas Witaed Nimitmai School
2016 – 2018	Highschool Diploma at Sarasas Witaed Nimitmai School
2019 – Present	King Mongkut's Institute of Technology Ladkrabang Major in Civil Engineering (International Program)

Author Biography

Name-Surname: Mr. Natthakan Manatsa

Date of Birth: 09th September 2001

Address: 119 Moo 11, Sankong,
Dokkhamtai, Phayao Province
Zip code. 56120

E-mail: Natthakan.manassa@gmail.com

Telephone: 094-932-6549

Educational record:

2013 – 2015 Middle school at Dokkhamtaiwittayakhom School

2016 – 2018 Highschool Diploma at Dokkhamtaiwittayakhom School

2019 – Present King Mongkut's Institute of Technology Ladkrabang
Major in Civil Engineering (International Program)

Author Biography

Name-Surname: Miss Pawiga Sihawong

Date of Birth: 21st September 2000

Address: 333/44 Bang Chalong, Bang Phli,
Samut Prakan Province
Zip code. 10540

E-mail: pawiga.sihawong@gmail.com

Telephone: 084-547-4350

Educational record:

2013 – 2015	Middle school at Bangpleepattanasuksalai School
2016 – 2018	Highschool Diploma at Ratwinit Bangkaeo School
2019 – Present	King Mongkut's Institute of Technology Ladkrabang Major in Civil Engineering (International Program)