# UTILIZATION OF BITUMINOUS FLY ASH FOR HOLLOW CONCRETE BLOCK PRODUCTION

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Thesis
entitled

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UTILIZATION OF BITUMINOUS FLY ASH FOR HOLLOW CONCRETE BLOCK PRODUCTION

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ABSTRACT

The objective of this research was to study the utilization of bituminous fly ash to replace cement in producing hollow concrete block. The ratio of cement to limestone crushing rock were 1 : 5 (by weight). The replacement of cement by bituminous fly ash was assigned to be 0%, 20%, 40%, 50%, 60% and 70%. Samples were measured for compressive strength at 3, 7 and 14 days for appropriate curing time. Water absorption, thermal conductivity and leaching of heavy metal from hollow concrete block were measured to select suitable bituminous fly ash proportion. Finally, the unit cost of hollow concrete block was analyzed.

It was found that the compressive strength in all curing times decreased (P-value<0.05) when bituminous fly ash proportion increased. The appropriate curing time was selected at 7 days, since at this point the compressive strength value of hollow concrete block was within the requirement of safety factor. The water absorption was increased (P-value<0.001) when bituminous fly ash proportion increased. The thermal conductivity was decreased (P-value<0.001) when bituminous fly ash proportion increased. The leaching of heavy metal, when tested for nickel, was increased (P-value=0.01) when bituminous fly ash proportion increased.

The suitable replacement of cement by bituminous fly ash was 70% (by weight), since the greatest volume of Portland cement could be reduced. The hollow concrete block properties were within the requirement of standard TIS 58-2533. It has compressive strength of 45 $kg/cm^2$ and water absorption of 14.5%. Also, the leaching of heavy metal, parameters tested, was acceptable within the standard in the Annoucement of Industry Ministry (B.E. 2548). Finally, the unit costs of hollow concrete block were reduced 0.23 baht/piece when compared to the cost of general hollow concrete block.

KEY WORDS: BITUMINOUS FLY ASH / PORTLAND CEMENT / LIMESTONE CRUSHING ROCK / HOLLOW CONCRETE BLOCK / HEAVY METAL

125 pages

การประยุกต์ใช้เถ้าลอยบิทูมินัสเป็นส่วนผสมในการผลิตคอนกรีตบล็อกกลวง

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บทคัดย่อ

งานวิจัยเรื่องนี้มีวัตถุประสงค์เพื่อศึกษาการนำเถ้าลอยที่เหลือจากการเผาถ่านหินบิทูมินัสมาเป็นส่วนผสมแทนที่ซีเมนต์บางส่วนในการผลิตคอนกรีตบล็อกกลวง โดยจะใช้อัตราส่วนปูนซีเมนต์ต่อหินฝุ่นเท่ากับ 1 : 5 โดยน้ำหนัก และแทนที่ซีเมนต์ด้วยเถ้าลอยบิทูมินัสที่อัตราส่วนเท่ากับ 0%, 20%, 40%, 50%, 60% และ 70% โดยน้ำหนัก ทั้งนี้จะพิจารณาจากค่าการรับแรงอัดที่ระยะเวลาการบ่ม 3, 7 และ 14 วัน เพื่อหาระยะเวลาการบ่มที่เหมาะสม จากนั้นนำไปทดสอบ ค่าการดูดซึมน้ำ, ค่าการนำความร้อน และ ค่าการชะละลายของโลหะหนัก เพื่อหาอัตราส่วนของเถ้าลอยบิทูมินัสที่เหมาะสม แล้วจึงนำไปวิเคราะห์เปรียบเทียบต้นทุนการผลิต

จากการทดลองพบว่า ค่ากำลังรับแรงอัดของก้อนคอนกรีตบล็อกที่ทุกระยะเวลาการบ่ม มีค่าลดลงอย่างมีนัยสำคัญทางสถิติ (P-value <0.05) เมื่อมีการแทนที่ซีเมนต์ด้วยเถ้าลอยบิทูมินัสที่อัตราส่วนเพิ่มขึ้น ทั้งนี้พบว่าระยะเวลาการบ่มที่เหมาะสมคือ 7 วัน เนื่องจากค่ากำลังรับแรงอัดมีค่าสูงกว่าระดับความปลอดภัย เมื่อทำการทดสอบคุณสมบัติต่างๆ พบว่าการดูดซึมน้ำมีค่าสูงขึ้นอย่างมีนัยสำคัญทางสถิติ (P-value <0.001) เมื่อมีการแทนที่ซีเมนต์ด้วยเถ้าลอยบิทูมินัสที่อัตราส่วนเพิ่มขึ้น และค่าสัมประสิทธิ์การนำความร้อนมีค่าลดลงอย่างมีนัยสำคัญทางสถิติ (P-value <0.001) เมื่อมีการแทนที่ซีเมนต์ด้วยเถ้าลอยบิทูมินัสที่อัตราส่วนเพิ่มขึ้น ขณะที่ปริมาณการชะละลายของนิกเกิลจากคอนกรีตบล็อกมีค่าสูงขึ้นอย่างมีนัยสำคัญทางสถิติ (P-value =0.01) เมื่อมีการแทนที่ซีเมนต์ด้วยเถ้าลอยบิทูมินัสที่อัตราส่วนเพิ่มขึ้น

อัตราส่วนการแทนที่ซีเมนต์ด้วยเถ้าลอยบิทูมินัสที่เหมาะสมคือที่ 70 % โดยน้ำหนัก เนื่องจากสามารถลดปริมาณการใช้ปูนซีเมนต์ได้มากที่สุด โดยคอนกรีตบล็อกกลวงที่ผลิตได้มีคุณสมบัติอยู่ในเกณฑ์ที่มาตรฐาน มอก 58-2533 กำหนด โดยมีค่าการรับแรงอัดเท่ากับ 45 kg/cm$^2$ และค่าการดูดซึมน้ำเท่ากับ 14.5 % อีกทั้งปริมาณการชะละลายของโลหะหนักที่ตรวจสอบมีค่าไม่เกินข้อกำหนดตามประกาศกระทรวงอุตสาหกรรม ปี พ.ศ. 2548 และเมื่อพิจารณาต้นทุนการผลิตพบว่า คอนกรีตบล็อกที่ผลิตจากสัดส่วนเถ้าลอยบิทูมินัสที่ 70 % มีต้นทุนการผลิตที่ต่ำกว่าคอนกรีตบล็อกที่ผลิตตามอัตราส่วนของโรงงาน 0.23 บาท/ก้อน

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# CHAPTER I
# INTRODUCTION

## 1.1 Statement of the Problem

At present, coal is important power resource for the growth of industry. Data from Energy Policy and Planning Office, Ministry of Energy, Thailand, in 2006 showed that usage of coals were about 30 million ton. Coals usage was mainly in electrical generating plant. It was about 19 million ton and about 11 million ton used in general industry (EPPO, 2006).

In industry, the majority of fuel is coal. Imported coals, such as Bituminous and Anthracite coal, have been increased continuously. These coals have been inexpensive and high-quality. Coals have been imported from China and Indonesia. Especially, the Bituminous coals have been imported mostly (Narongchai, 2000). The import statistic of bituminous coals in the year 2006 were showed quantity of bituminous coals from foreign country about 5.7 million ton. Moreover, trend increases in the future (The Customs Department, Thailand, 2006). Fly ash is inorganic residue after burning coal for fuel. The fly ashes have been rapidly accumulated and cause problems of disposal (Narongchai, 2000).

Bituminous fly ashes are industrial waste generated from bituminous coal-fired used in the process of a factory. The bituminous fly ashes in this research were brought from Samut Prakarn textile factory. Data of a factory in the year 2007 showed quantity of bituminous fly ashes about 600 kg/day. It remained a problem for solid waste disposal which greatly affects the environment. The chemical composition of bituminous fly ashes composes mainly silica ($SiO_2$) and alumina ($Al_2O_3$). From its component, bituminous fly ashes have the property as the pozzolan. When bituminous fly ashes mix with cement, it will cause binder (Naik et al., 1995). Utilization of bituminous fly ashes is another choice to replace cement and aggregate in construction materials. This feasibility study will reduce the amount of bituminous fly ashes to be disposed of.

Hollow concrete block is general construction materials used convenient is in a variety of civil construction and industrial application. The majority of the product has been used in non-load-bearing structure form such as walls, partitions and chimneys. Generally, the main concrete block has been produced from three materials. They are cement, limestone crush rock and water in proportion about 2 : 10 : 1 by volume . The conventional size of hollow concrete block has been used extensively at 7 × 19 × 39 cm. The average weight for one piece is about 7 kilogram (Bundit, 2548).

Utilization of bituminous fly ashes from bituminous coal-fired for fuel is another choice to replace cement in hollow concrete block for the construction. It will reduce the amount of bituminous fly ashes to be disposed of, therefore adding more valuable benefit to its use.

The objective of this research is to study the optimum proportion of bituminous fly ash for replacing cement in hollow concrete block production, also to determine the leaching of heavy metals from hollow concrete block production. It is hopeful that the result from this research can be developed for a large scale manufacture in the future.

## 1.2 Research Objectives

### 1.2.1 General Objective

To study the feasibilities of replacing cement by bituminous fly ash in hollow concrete block production.

### 1.2.2 Specific Objectives

1. To analyze the physical properties and chemical compositions of bituminous fly ash.
2. To compare the compressive strength of different mixing ratio and curing time of hollow concrete block.
3. To compare the water absorption and thermal conductivity of different mixing ratio of hollow concrete block.
4. To determine the optimum proportion of bituminous fly ash and cement in hollow concrete block production.
5. To study the leachability of heavy metals from hollow concrete block.
6. To determine unit cost of hollow concrete block production.

## 1.3 Research Hypotheses

**1.3.1** Bituminous fly ash has a binding property when mixed with cement.

**1.3.2** The compressive strength of hollow concrete block decreases when the proportion of bituminous fly ash increases.

**1.3.3** The compressive strength of hollow concrete block increases when the curing time increases.

**1.3.4** The water absorption increases when the proportion of bituminous fly ash increases.

**1.3.5** The thermal conductivity of hollow concrete block decreases when the proportion of bituminous fly ash increases.

**1.3.6** The concentration of heavy metals increases when the proportion of bituminous fly ash increases.

## 1.4 Research Variables

**1.4.1 Independent Variable**

- Proportion of bituminous fly ash to cement
- Curing time of concrete

**1.4.2 Dependent Variables**

- Compressive strength
- Water absorption
- Thermal conductivity
- Concentration of heavy metals

**1.4.3 Control Variables**

- Type of Portland cement
- Size of limestone crushing rock
- Water to Binder (W/B)
- Proportion of cement to limestone crushing rock

## 1.5 Scope of the Study

**1.5.1** The bituminous fly ash used in this study was derived from burning bituminous coal for fuel in a Samut Prakarn textile factory.

**1.5.2** The mixture of raw material for hollow concrete block production was cement, water and limestone crushing rock.

**1.5.2** Water to Binder (cement + bituminous fly ash) ratio was controlled in the range of 0.5 to 0.7.

**1.5.4** Standard for hollow non-load-bearing concrete masonry units was in accordance with the Thailand Industrials Standard (TIS 58-2533).

**1.5.5** Size of the hollow concrete block in the study was 7 × 19 × 39 cm.

**1.5.6** The physical and mechanical properties of hollow concrete block including water absorption and compressive strength (curing time of 3, 7 and 14 day) followed the standard of Thailand Industrials Standard in TIS 109-2517.

**1.5.7** The leachability of heavy metal in hollow concrete block followed the standard in the Annoucement of Industry Ministry (B.E. 2548).

## 1.6 Definitions of Keywords

**1.6.1 Bituminous fly ash:** Fine solid particles of bituminous ash carried into the air during combustion and collected by cyclone.

**1.6.2 Portland cement:** Hydrated cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicate, usually containing one or more forms of calcium sulfate as an inter ground addition.

**1.6.3 Aggregate:** The granular mineral material (such as sand, limestone crushing rock) used with cement to make concrete.

**1.6.4 Limestone crushing rock:** Sedimentary rocks that are made from crushing rock.

**1.6.5 Hollow concrete block:** Primarily used as a building material in the construction of walls, composing cement and limestone crushing rock.

**1.6.6 Pozzolan:** means the material is a siliceous and aluminous material which in itself posses little or no binder properties but will, in finely divided from and in the presence of moistures, chemically react with calcium hydroxide in cement at ordinary temperature to form compounds possessing binder properties.

**1.6.7 Binder:** an ingredient used to bind together two or more other materials in mixtures. Its two principal properties are adhesion and cohesion.

**1.6.8 Solidification:** means the process in which materials are added to the waste to produce a solid.

**1.6.9 Cementitious:** inorganic material or a mixture of inorganic materials that sets and develops strength by chemical reaction with water by formation of hydrates and is capable of doing so under water.

**1.6.10 Curing:** defined to action taken to maintain moisture and temperature condition in a freshly-placed cementitious mixture to allow hydraulic cement hydration and (if applicable) pozzolanic reaction to occur so that the potential properties of the mixture may develop.

**1.6.11 Water-binder ratio:** the portion between water and cement + bituminous fly ash (by weight).

**1.6.12 Compressive strength:** the stress pressure that start causing damages to the study work.

**1.6.13 Water absorption:** Physical property of material to absorb water during soaking. The test specimens determine the difference in weight indicates the amount of water absorbed by the concrete and from which percentage of water absorption is determined.

**1.6.14 Thermal conductivity:** is the property of a material that indicates its ability to conduct heat.

**1.6.15 Thai Industrial Standard (TIS):** is the standard for Thai industrial product set by the announcement of the Industrial Ministry.

**1.6.16 American Society for testing and material (ASTM):** is standard of The United States of America and used extensively for technical standards for materials, products, system, and services.

## 1.7 Conceptual Framework

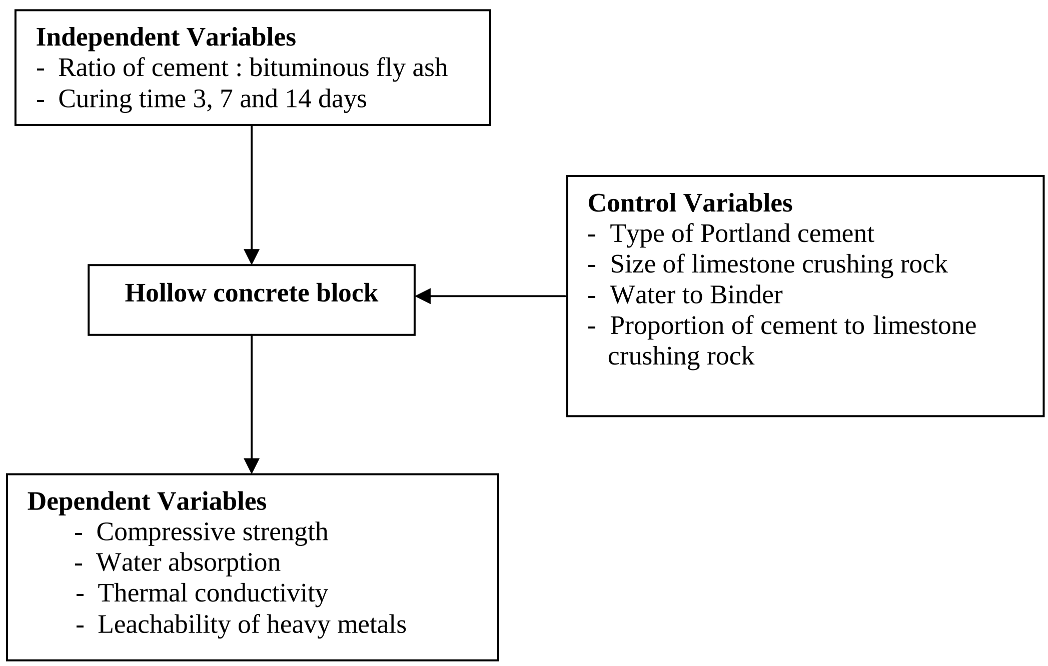



**Figure1.1** Conceptual framework

# CHAPTER II
# LITERATURE REVIEW

## 2.1 Coal and its use

The coal is a natural fossil fuel. It formed in organic matter were preserved by water and mud from oxidization and biodegradation, thus sequestering atmospheric carbon. Coal is a readily combustible black or brownish-black rock. It is a sedimentary rock, but the harder forms, such as anthracite coal, can be regarded as metamorphic rocks because of later exposure to increase temperature and pressure. It is composed primarily of carbon and hydrogen along with small quantities of other elements, notably sulfur. It is the largest source of fuel for generation of electricity world-wide. Coal is slightly ahead of petroleum and about double that natural gas. Coal is extracted from the ground by coal mining, either underground mining or open pit mining (surface mining) (Smith, 1993).

### 2.1.1 Type of coal

As geological processes apply pressure to dead biotic matter over time, under suitable conditions it is transformed successively into

2.1.1.1 Lignite coal

Lignite coal also referred to brown coal. It is the lowest rank of coal and used almost exclusively as fuel for steam-electric power generation. Jet is a compact form of lignite that is sometimes polished and has been used as an ornamental stone since the Iron Age.

2.1.1.2 Sub-bituminous coal

Sub-bituminous coal, whose properties range from those of lignite to those of bituminous coal and are used primarily as fuel for steam-electric power generation. Additionally, it is an important source of light aromatic hydrocarbons for the chemical synthesis industry.

2.1.1.3 Bituminous coal

Bituminous coal, a dense mineral, black but sometimes dark brown, often with well-defined bands of bright and dull material, used primarily as fuel in steam-electric power generation, with substantial quantities also used for heat and power applications in manufacturing and to make coke.

2.1.1.4 Anthracite coal

Anthracite coal, the highest rank; a harder, glossy, black coal used primarily for residential and commercial space heating. It may be divided further in to metamorphically altered bituminous coal and petrified oil, as from the deposits in Pennsylvania.

### 2.1.2 Utilization of coal

2.1.2.1 For electric power

The coal is used to generate roughly half of all electricity produced in the United States. Besides electric utility companies, industries and businesses with their own power plants use coal to generate electricity. The power plants are burn coal to make steam. The steam turns turbines which generate electricity.

2.1.2.2 For industry

A variety of industries use coal as heat energy. Separated ingredients of coal (such as methanol and ethylene) are used in making plastics, tar, synthetic fibers, fertilizers, and medicines. The concrete and paper industries also burn large amounts of coal.

2.1.2.3 For making steel

The coal is baked in hot furnaces to make coke, which is used to smelt iron ore into iron needed for making steel. It is the very high temperatures created from the use of coke that gives the strength and flexibility to steel. Its product such as bridges, buildings, and automobiles.

### 2.1.3 Quantity of coal used in the world

The coal is primarily used as a solid fuel to produce electricity and heat combustion. World coal consumption is about 6.2 billion tons annually about 75% is used for the production of electricity. China produced 2.38 billion tons in 2006 and India produced about 447.3 million tons in 2006. About 70% of China's electricity comes from coal. The USA consumes about 1.053 billion tons of coal each year, using 90% of it for generation of electricity. The world in total produced 6.19 billion tons of coal in 2006 (Höök M., 2006)

### 2.1.4 Used of coal in Thailand

2.1.4.1 The coal is in country

In Thailand mostly lignite and sub-bituminous and has played an important role as a major energy source for decades. In 2001 the total reserve was 2,155 million tons. Of this, 1,124 million tons, or 52.16% was from the Mae Moh basin operated by the Electricity Generating Authority of Thailand (EGAT). The Krabi basin has a measured reserve of 112 million tons. In southern Thailand are the Saba Yoi basin in Songkhla Province, with a measured reserve of 350 million tons, and the Sin Pun basin, with a measured reserve of 91 million tons. In the north, there are the following basins: Wiang Haeng, Ngao and Mae Tha, with a measured reserve of 93, 48 and 25 million tons respectively (EPPO, 2002).

In 2002, lignite production was 19.6 million tons, 76% of which came from the Mae Moh Mine of EGAT and was used in power generation. The remaining 24% was produced by private mines and used by the industrial sector, including cement, pulp & paper, food processing and tobacco-curing industries. Coal consumption by the industrial sector increased at an average rate of 22.2%. More than 70% was used as fuel in cement manufacturing (EPPO, 2002).

2.1.4.2 Imported of coal

The past ten years, Thailand has still imported more coal and coal products from various countries during the period. Which most of the imported coals are bituminous. Majority of the imported coal are import from Indonesia, Australia, Burma, Laos, Vietnam and China which the coal from Indonesia has large amount most. The quantity of imported coal from year 2003 – 2007 is shown in Table 2.1.

**Table 2.1** Quantity of imported coal

| Year | Imported coal (ton) |
|---|---|
| 2003 | 5,747,190 |
| 2004 | 7,529,004 |
| 2005 | 9,459,251 |
| 2006 | 11,157,647 |
| 2007 | 18,037,102 |

**Source:** The Customs Department, Thailand, 2007

### 2.1.5 Coal combustion system

2.1.5.1 Pulverized coal combustion (PC)

PC is a coal burning technique in which the coal is pulverized before being ignited. It is the most common method of burning coal for power generation. The basic idea of a firing system using pulverized coal is to use the whole volume of the furnace for the combustion of solid fuels. Coal is ground to the size of a fine grain, mixed with air and burned in the flue gas flow. The PC was used for boiler that generates thermal energy. This type of boiler dominates the electric power industry, providing steam to drive large turbines. Pulverized coal provides the thermal energy which produces about 50% of the world's electric supply **(**Jones, 1994).

2.1.5.2 Fluidized bed combustion (FBC)

FBC is a combustion technology used in power plants. FBC plants are more flexible than conventional plants in that they can be fired on coal. Fluidized beds suspend solid fuels on upward-blowing jets of air during the combustion process. The result is a turbulent mixing of gas and solids. The tumbling action, much like a bubbling fluid, provides more effective chemical reactions and heat transfer. FBC reduces the amount of sulfur emitted in the form of $SO_x$ emissions. Limestone is used to precipitate out sulfate during combustion, which also allows more efficient heat transfer from the boiler to the apparatus used to capture the heat energy (usually water tubes). The heated coming in direct contact with the tubes (heating by conduction) increases the efficiency. Since this allows coal plants to burn at cooler temperatures, less $NO_x$ is also emitted. However, burning at low temperatures also causes increased polycyclic aromatic hydrocarbon emissions. FBC boilers can burn fuels other than coal, and the lower temperatures of combustion (800 °C / 1500 °F ) have other added benefits as well **(**Jones, 1994).

## 2.2 Fly Ash and its use

Fly ash is produced from coal-fired electric and steam generating plants. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extract heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash or slag, fall to the bottom of the combustion chamber, while the lighter fine ash particles, termed fly ash, remain suspended in the flue gas. Prior to exhausting the flue gas, powdery particulate material that is carried off in the flue gas and usually collected from the flue gas by means of electrostatic precipitators, baghouses, or mechanical collection devices such as cyclones in Figure 2.1.

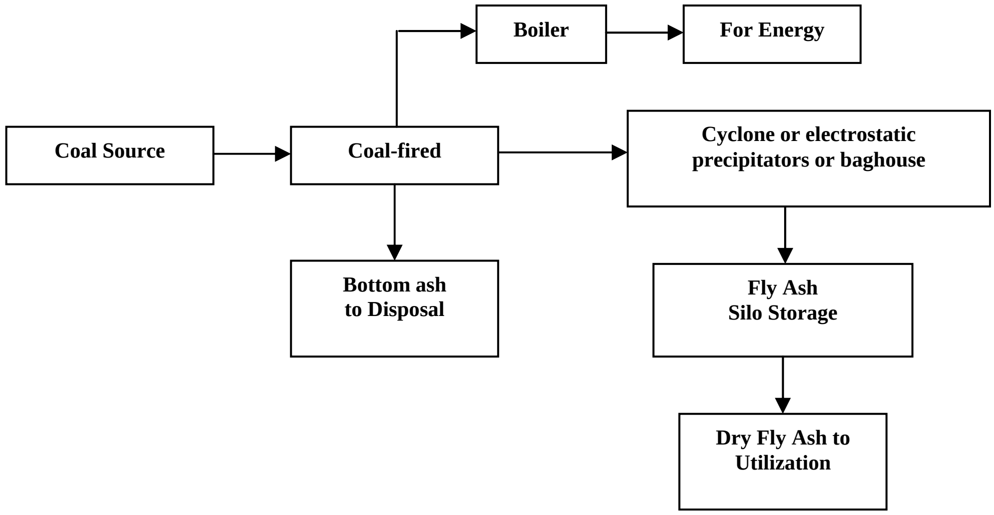



**Figure 2.1** The fly ash generation process

The components of the fly ash produced vary considerably, but all fly ash includes substantial amounts of silica (silicon dioxide, $SiO_2$) (both amorphous and crystalline) and lime (calcium oxide, CaO). Fly ash is commonly used to supplement Portland cement in concrete production, where it can bring both technological and economic benefits, and is increasingly finding use in synthesis of polymers and zeolites (American Coal Ash Association, 1997).

### 2.2.1 Physical properties of fly ash

Fly ash consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature. The carbonaceous material in fly ash is composed of angular particles. The particle size distribution of most bituminous coal fly ashes is generally similar to that of a silt (less than a 0.075 mm or No. 200 sieve). Although sub-bituminous coal fly ashes are also silt-sized, they are generally slightly coarser than bituminous coal fly ashes.

The specific gravity of fly ash usually ranges from 2.1 to 3.0, while its specific surface area (measured by the Blaine air permeability method) may range from 170 to 1000 $m^2$/kg.

The color of fly ash can vary from tan to gray and gray to black, depending on the amount of unburned carbon in the ash. The lighter the color was the lower the carbon content. Lignite or sub-bituminous fly ashes are usually light tan to buff in color, indicating relatively low amounts of carbon as well as the presence of some lime or calcium. Bituminous fly ashes are usually some shade of gray, with the lighter shades of gray generally indicating a higher quality of ash (American Coal Ash Association, 1997).

### 2.2.2 Chemical properties of fly ash

The chemical properties of fly ash are influenced to a great extent by those of the coal burned and the techniques used for handling and storage. There are basically four types, or rank, of coal. Each of which varies in terms of its heating value, its chemical composition, ash content, and geological origin. The four types, or ranks, of coal are anthracite, bituminous, sub-bituminous, and lignite. In addition to being handled in a dry, conditioned, or wet form. Fly ash is also sometimes classified according to the type of coal which the ash was derived.

The principal components of bituminous coal fly ash are silica, alumina, iron oxide, and calcium, which vary amounts of carbon, as measured by the loss on ignition (LOI). Lignite and sub-bituminous coal fly ashes are characterized by higher concentrations of calcium and magnesium oxide and reduced percentages of silica and iron oxide, as well as a lower carbon content, compared with bituminous coal fly ash. Very little anthracite coal is burned in utility boilers, so there are only small amounts of anthracite coal fly ash.

Table 2.2 compares the normal range of the chemical constituents of bituminous coal fly ash with those of lignite coal fly ash and sub-bituminous coal fly ash. From the table, it is evident that lignite and sub-bituminous coal fly ashes have a higher calcium oxide content and lower loss on ignition than fly ashes from bituminous coals. Lignite and sub-bituminous coal fly ashes may have a higher concentration of sulfate compounds than bituminous coal fly ashes (American Coal Ash Association, 1997).

**Table 2.2** Normal range of chemical composition for fly ash produced from different coal types (expressed as percent by weight)

| Component(%) | Bituminous | Subbituminous | Lignite |
|---|---|---|---|
| $SiO_2$ | 20-60 | 40-60 | 15-45 |
| $Al_2O_3$ | 5-35 | 20-30 | 20-25 |
| $Fe_2O_3$ | 10-40 | 4-10 | 4-15 |
| CaO | 1-12 | 5-30 | 15-40 |
| MgO | 0-5 | 1-6 | 3-10 |
| $SO_3$ | 0-4 | 0-2 | 0-10 |
| $Na_2O$ | 0-4 | 0-2 | 0-6 |
| $K_2O$ | 0-3 | 0-4 | 0-4 |
| LOI (%) | 0-15 | 0-3 | 0-5 |

**Remark:** LOI (Loss on Ignition) is a test used in inorganic analytical chemistry

### 2.2.3 Class of fly ash

The ASTM C618-08 (Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete) specification is the most widely used because it covers the use of fly ash as a pozzolan or mineral admixture in concrete. The two classes of fly ashes are Class F and Class C. Class F is pozzolanic fly ash normally produced from burning anthracite or bituminous coal. Class C is pozzolanic and cementitious fly ash normally produced from burning lignite or subbituminous coal.

The chief difference between Class F and Class C fly ash is in the summation of amount of the silica, alumina, and iron content in the fly ash. In Class F and Class C of fly ash specification is the summation of amount of the silica, alumina, and iron content in the fly ash for 70 and 50 percent respectively.

The strength activity index is indicator to the occurrence of pozzolanic reaction. Comparison compressive strength is percent of mortar mixed with fly ash and control mortar at curing time for 7 and 28 day.

The chemical and physical requirements listed in the ASTM C618-08 specification for identified as pozzolan material. It was shown in Table 2.3.

**Table 2.3** The chemical and physical requirements listed in the ASTM C618-08 specification for identified as pozzolan material

| ASTM Specification C618-08 Chemical and Physical Specifications | | |
|---|---|---|
| | Mineral Admixture Class | |
| | F | C |
| **Chemical Requirements** | | |
| Silicon dioxide, Aluminum oxide, Iron oxide ($SiO_2 + Al_2O_3 + Fe_2O_3$) min. % | 70 | 50 |
| Sulfur trioxide ($SO_3$), max. % | 5.0 | 5.0 |
| Moisture content, max. % | 3.0 | 3.0 |
| Loss on ignition, max. % | 6.0 | 6.0 |
| Available alkalies as $Na_2O$, max % | 1.5 | 1.5 |
| **Physical Requirements** | | |
| Fineness, max. % retained on 325-mesh sieve | 34 | 34 |
| **Strength Activity Index Portland Cement** | | |
| 7-day, min. % control | 75 | 75 |
| 28-day, min % control | 75 | 75 |
| Water requirement, max. % of control | 105 | 105 |
| Autoclave expansion, soundness, max. % | 0.8 | 0.8 |

### 2.2.4 Reaction of fly ash with cement

Reaction of fly ash with cement is reaction of silica in fly ash with calcium hydroxide in cement. This is called a "Pozzolanic reaction" which creates an increased amount of CSH binder. It causes the concrete strength increase. The pozzolanic reaction may be slower than the rest of the reactions which occur during cement hydration

The following pozzolanic reaction occurs.

$$xCH + yS + zH \longrightarrow C_xS_yH_{X+Z}$$

| | | |
|---|---|---|
| xCH | = | Calcium hydroxide |
| yS | = | Silica in pozzolan |
| zH | = | Water |
| $C_xS_yH_{X+Z}$ | = | Calcium-silicate hydrate |

## 2.3 Aggregates

Since at the most of mixture in concrete is aggregate, it is not surprising that is quality is of considerable importance. The aggregate was originally viewed as an inert material dispersed throughout the cement paste largely for economic reason. Properties of concrete attributable to aggregate include unit weight, strength, modulus of elasticity, creep, thermal coefficient of expansion, soundness, fire resistance, and resistance to wear and abrasion. So, then must consider properties of aggregate.

1) Particle shape and surface is important for workability and affect to compressive strength of concrete block.

2) Strength of aggregate dependent to strength of original rack.

3) The particle size distributions of aggregate are important for workability and compressive strength of concrete block. The particle size distributions are requirement by standard method for concrete aggregates from according to Thai Industrial Standard No. TIS 566 – 2528 as show in Table 2.4.

**Table 2.4** The particle size distributions of aggregate

| Sieve size | Percent Passing by weight | | | |
|---|---|---|---|---|
| | **I** | **II** | **III** | **IV** |
| 9.5 – mm. (3/8-in.) | 100 | 100 | 100 | 100 |
| 4.75 – mm. (No.4) | 90 – 100 | 90 – 100 | 90 – 100 | 95 – 100 |
| 2.36 – mm. (No.8) | 60 – 95 | 75 – 100 | 85 – 100 | 95 – 100 |
| 1.18 – mm. (No.16) | 30 – 70 | 55 – 90 | 75 – 100 | 90 – 100 |
| 600 – µm (No. 30) | 15 – 34 | 35 – 59 | 60 – 79 | 80 – 100 |
| 300 – µm (No. 50) | 5 – 20 | 8 – 30 | 12 – 40 | 15 – 50 |
| 150 – µm (No. 100) | 0 – 10 | 0 – 10 | 0 – 10 | 0 – 15 |

**Source:** Thai Industrial Standard Institute**,** TIS 566 – 2528

## 2.4 Portland cement

The properties of concrete depend on the quantities and qualities of its components. Because cement is the most active component of concrete and usually has the greatest unit cost, its selection and proper use are important in obtaining most economically the balance of properties desired for any particular concrete mixture.

ASTM C 150 defines portland cement as hydraulic cement (cement that not only hardens by reacting with water but also forms a water-resistant product) produced by pulverizing clinkers consisting essentially of hydraulic calcium silicates.

Usually it contains one or more of the forms of calcium sulfate as an inter ground addition. Clinkers are nodules (diameters, 0.2-1.0 inch [5-25 mm]) of a sintered material that is produced when a raw mixture of predetermined composition is heated to high temperature. The low cost and widespread availability of the limestone, shales, and other naturally occurring materials make portland cement one of the lowest-cost materials widely used over the last century throughout the world. Concrete becomes one of the most versatile construction materials available in the world (Sedthabut, 1996).

### 2.4.1 Type of portland cement

Different types of portland cement are manufactured to meet different physical and chemical requirements for specific purposes as follows

2.4.1.1 Type I Ordinary Portland cement

Is a general purpose Portland cement suitable for all uses where the special properties of other types are not required. It is used where cement or concrete is not subject to specific exposures, such as sulfate attack from soil or water, or to an objectionable temperature rise due to heat generated by hydration. Its uses include pavements and sidewalks, reinforced concrete buildings, bridges, railway structures, tanks, reservoirs, culverts, sewers, water pipes and masonry units.

2.4.1.2 Type II Modified Portland cement

Portland cement is used where precaution against moderate sulfate attack is important, as in drainage structures where sulfate concentrations in groundwaters are higher than normal but not unusually severe. Type II cement will usually generate less heat at a slower rate than Type I. With this moderate heat of hydration (an optional requirement), Type II cement can be used in structures of considerable mass, such as large piers, heavy abutments, and heavy retaining walls. Its use will reduce temperature rise, an important quality when the concrete is placed in warm weather.

2.4.1.3 Type III High early strength

Is a high-early strength Portland cement that provides high strengths at an early period, usually a week or less. It is used when forms are to be removed as soon as possible, or when the structure must be put into service quickly. In cold weather, its use permits a reduction in the controlled curing period. Although richer mixtures of Type I cement can be used to gain high early strength, may provide it more satisfactorily and more economically.

2.4.1.4 Type IV Low heat Portland cement

Is a low heat of hydration cement for use where the rate and amount of heat generated must be minimized. It develops strength at a slower rate than Type I cement. Type IV portland cement is intended for use in massive concrete structures, such as large gravity dams, where the temperature rise resulting from heat generated during curing is a critical factor.

2.4.1.5 Type V Sulphate resistance Portland cement

Is a sulfate-resisting cement used only in concrete exposed to severe sulfate action principally where soils or ground waters have a high sulfate content. The following Table describes sulfate concentrations requiring the use of Type V Portland cement. Low Tricalcium Aluminate content, generally 5% or less, is required when high sulfate resistance is needed.

### 2.4.2 Chemical component of Portland cement

Properties of portland cement depends chemical component. The most chemical component is oxides of elements. The proportion of oxides in Portland cement is show in Table 2.5.

**Table 2.5** Oxides in elements of Portland cement

| **Oxides of elements** | **Percent by weight** |
|---|---|
| Calcium Oxide (CaO) | 60.0 – 67.0 |
| Silicon Dioxide ($SiO_2$) | 17.0 – 25.0 |
| Aluminium Oxide ($Al_2O_3$) | 3.0 – 8.0 |
| Ferric Oxide ($Fe_2O_3$) | 0.5 – 0.6 |
| Sulfer Trioxide ($SO_3$) | 1.0 – 3.0 |
| Magnesium Oxide (MgO) | 0.5 – 5.5 |
| Alkalies Oxide ($Na_2O + 0.658K_2O$) | 0.5 – 1.3 |
| Titanium Oxide ($TiO_2$) | 0.1 – 0.4 |
| Phosphorus Oxide ($P_2O_5$) | 0.1 – 0.2 |

Oxides of Portland cement will be formed reaction in form of chemical compound in the Table 2.6 as follows.

**Table 2.6** The chemical compound constituents of Portland cement.

| **Chemical Name** | **Chemical compound** | **Percent by weight follow to type of cement** | | | | |
|---|---|---|---|---|---|---|
| | | I | II | III | IV | V |
| Tricalcium Silicate ($C_3S$) | $3CaO{\cdot}SiO_2$ | 50 | 45 | 60 | 25 | 40 |
| Dicalcium Silicate ($C_2S$) | $2CaO{\cdot}SiO_2$ | 25 | 30 | 15 | 50 | 40 |
| Tricalcium Aluminate ($C_3A$) | $3CaO{\cdot}Al_2O_3$ | 12 | 7 | 10 | 5 | 4 |
| Tetracalcium Aluminoferrite ($C_4AF$) | $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$ | 8 | 12 | 8 | 4 | 4 |

### 2.4.3 Reaction of cement with water

When the portland cement is mixed with water its chemical compound constituents undergo a series of chemical reactions that cause it to harden. These chemical reactions all involve the addition of water to the basic chemical compounds listed in Table 2.6. This chemical reaction with water is called "hydration". Each one of these reactions occurs at a different time and rate. Together, the results of these reactions determine how portland cement hardens and gains strength. The simplified reaction of portland cement with water may be expressed as:

**1) Hydration reaction of Tricalcium Silicate**

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$$

**2) Hydration reaction of Dicalcium Silicate**

$$2(2CaO.SiO_2) + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2$$

**3) Hydration reaction of Tricalcium Aluminate**

$$3CaO.Al_2O_3 + 6H_2O \rightarrow 3CaO.Al_2O_3.6H_2O$$

**4) Hydration reaction of Tetracalcium Aluminoferrite**

$$4CaO.Al_2O_3.Fe_2O_3 + CaSO_4.2H_2O + Ca(OH)_2 \rightarrow 3CaO(Al_2O_3.Fe_2O_3).3CaSO_4$$

### 2.4.4 Strength of Cement

The mechanical strength of hardened cements is the basic property of the material. Compressive strength is defined as the maximum stress sustained by the test specimen, i.e. the maximum load registered on the testing machine (P max) divided by the cross section area (A) of specimen

$$S = P\ max / A$$

The testing procedures have been standardized with respect to the shape, and dimensions of the specimen and the loading rate to avoid any anomalies in comparison.

The hydration causes the formation of gel particles. The bonding forces between the particles increase with the number of bond per unit volume and their strength. The water of hydration is responsible for strength development (Soroka, 1993).

## 2.5 Curing of Concrete

Adding water to Portland cement to form the water-cement paste that holds concrete together starts a chemical reaction that makes the paste into a bonding agent. This reaction, called hydration, produces a stone - like substance the hardened cement paste. Both the rate and degree of hydration, and the resulting strength of the final concrete, depend on the curing process that follows placing and consolidating the plastic concrete. Hydration continues indefinitely at a decreasing rate as long as the mixture contains water and the temperature conditions are favorable. Once the water is removed, hydration ceases and cannot be restarted (Neville, 1996).

Curing is the period of time from consolidation to the point where the concrete reaches its design strength. During this period will must take certain steps to keep the concrete moist and as near 73°F as practical. The properties of concrete, such as freeze and thaw resistance, strength, water tightness, wear resistance, and volume stability, cure or improve with age as long as maintain the moisture and temperature conditions favorable to continued hydration (Neville, 1996).

The length of time must protect concrete against moisture loss depends on the type of cement used, mix proportions, required strength, size and shape of the concrete mass, weather, and future exposure conditions. The period can vary from a few days to a month or longer. For most structural use, the curing period for cast-in-place concrete is usually 3 days to 2 weeks. This period depends on such conditions as temperature, cement type, mix proportions, and so forth. Bridge decks and other slabs exposed to weather and chemical attack usually require longer curing periods (Neville, 1996). Figure 2.2 shows how moist curing affects the compressive strength of concrete.

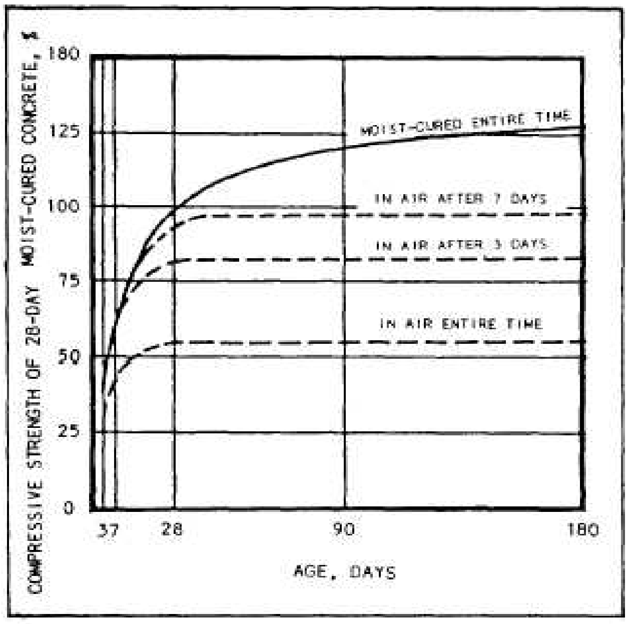



**Figure 2.2** The moist curing effect on compressive strength of concrete

## 2.6 Concrete masonry

One of the most common masonry units is the concrete block. It consists of hardened cement and may be completely solid or contain single or multiple hollows. It is made from convention cement mixes and various types of aggregate. These include sand, gravel, crushed stone, air-cooled slag, volcanic cinder, pumice, and "scotia" (refuse obtained from metal ore reduction and smelting). The term "concrete block" was formerly limited to only hollow masonry units made with such aggregates as sand, gravel, and crushed stone. Today, the term covers all types of concrete block-both hollow and solid – made with any kind of aggregate. Concrete blocks are also available with applied glazed surfaces, various pierced designs, and a wide variety of surface textures.

Although concrete block is made in many sizes and shapes (Figure 2.3) and in both modular and nonmodular dimensions, its most common unit size is 7 5/8 by 7 5/8 by 15 5/8 inches. This size is known as 8-by-8-by-16-inch block nominal size. All concrete block must meet certain specifications covering size, type, weight, moisture content, compressive strength, and other characteristics. Properly designed and constructed, concrete masonry walls satisfy many building requirement, including fire prevention, safety, durability, economy, appearance, utility, comfort, and acoustics (Koski, 1992).

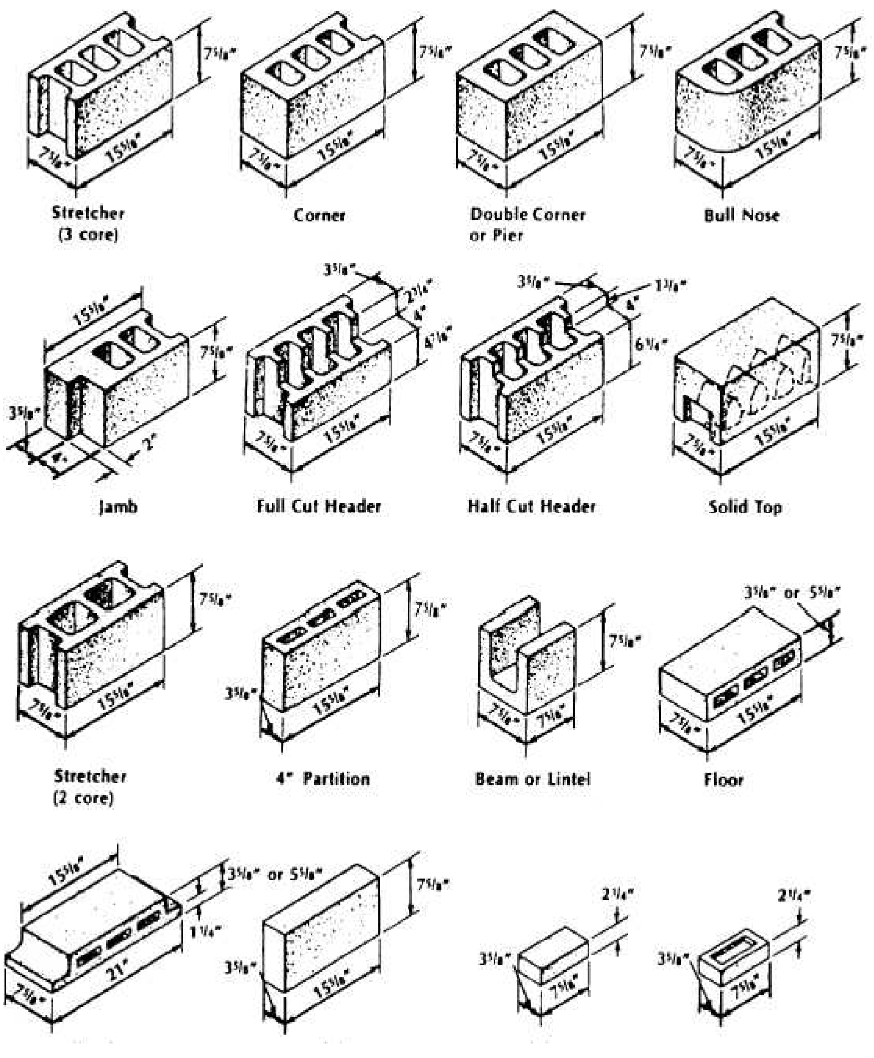



**Figure 2.3** Typical unit sizes and shapes of concrete masonry units

Concrete blocks are used in all types of masonry construction. The following are just a few of many examples:

- Exterior load-bearing walls (both below and above grade)
- Interior load-bearing walls

- Fire walls and curtain walls
- Partitions and panel walks
- Backing for brick, stone, and other facings
- Fireproofing over structural members
- Fire safe walls around stairwells, elevators, and enclosures
- Piers and columns
- Retaining walls
- Chimneys
- Concrete floor units

There are five main types of concrete masonry units:

- Hollow load-bearing concrete block
- Solid load-bearing concrete block
- Hollow non-load-bearing concrete block
- Concrete building tile
- Concrete brick

## 2.7 The criteria of Thai Industrial Standard

Thai Industrial Standard Institute has the criteria for hollow non-load-bearing concrete masonry units under TIS 58-2533.

### 2.7.1 Scope

Thai Industrial Standard specifies type and symbol, size and tolerances, materials, requirement, signal and label, sampling and criteria and testing for hollow non-load-bearing concrete masonry units.

### 2.7.2 Definition

For the purpose of this standard, the following definitions apply.

2.7.2.1 Hollow concrete block or Hollow concrete masonry unit: Hollow concrete masonry unit made from Portland cement, water and mineral aggregates with or without the inclusion of other materials for use in wall construct. These units have large hollow through of piece

2.7.2.2 Hollow non-load-bearing concrete masonry unit: These units for use in nonloadbearing exterior walls other than oneself weight.

2.7.2.3 Face – shell : Outside layer of hollow concrete block.

**2.7.3 Type**

Standard of hollow non-load-bearing concrete masonry is the following.

2.7.3.1 Control moisture unit.

2.7.3.2 Non-control moisture unit.

**2.7.4 Sizes and tolerances**

The thickness of shell is not less than 12 millimeter. The sizes of hollow non-load-bearing concrete masonry units shall comply with Table 2.7 which the tolerances less than ± 2 millimeter.

**Table 2.7** The standard sizes of Hollow concrete block.

| **Hollow non-load-bearing concrete masonry units** | |
|---|---|
| **Thickness × High × Long (millimeter)** | |
| 70 × 190 × 140 | 70 × 190 × 290 |
| 90 × 190 × 140 | 90 × 190 × 290 |
| 140 × 190 × 140 | 140 × 190 × 290 |
| 190 × 190 × 140 | 190 × 190 × 290 |
| 70 × 190 × 190 | 70 × 190 × 390 |
| 90 × 190 × 140 | 90 × 190 × 390 |
| 140 × 190 × 140 | 140 × 190 × 390 |
| 190 × 190 × 140 | 190 × 190 × 390 |

**Source:** Thai Industrial Standard Institute**,** 2533

### 2.7.5 Material

2.7.5.1 Cement: The cement used shall be selected from the following cements.

- Portland cement as specified Past 1. of TIS 15, standard for Portland cement: specification.

- Mixed cement as specified in TIS 80, Standard for mixed cement.

2.7.5.2 Aggregate: The aggregates shall only comply with TIS 566, Standard for concrete aggregates.

2.7.5.3 Other (if may): Air entraining, pigment, waterproofing and other used shall comply with relate to Thai industrial standard.

### 2.7.6 Requirement

2.7.6.1 Finish and Appearance

(1) The blocks shall be sound and free of cracks or other defects that interfere with the proper placement of the units or significantly impair the strength or permanence of the construction. Minor cracks incidental to the usual method of manufacture or minor chipping resulting from customary methods of handling in shipment and delivery are not grounds for rejection.

(2) Where blocks are to be used in exposed walls construction, the face or faces that are to be exposed shall not show chips or cracks, not otherwise permitted, or other imperfections when viewed from a distance of not less than 6.1 meter under diffused lighting.

- Five percent of a shipment containing chips, not larger than 25.4 millimeter in any dimension, or cracks not wider than 0.5 millimeter and not longer than 25% of the nominal height of the unit is permitted.

(3) The color and texture of the blocks shall be specified by the purchaser. The finished surfaces that will be exposed in place shall conform to an approved sample consisting of not less than four units, representing the range of texture and color permitted.

(4) Non-load-bearing concrete masonry units shall be clearly marked in a manner to preclude their use as load bearing units.

2.7.6.2 Compressive strength

At the time of delivery to the purchaser, units shall conform to the compressive strength requirements prescribed in Table 2.8.

**Table 2.8** Compressive strength requirements

| **Compressive Strength (average net area) (Kg/cm$^2$)** | |
|---|---|
| Average of 5 units | Individual unit |
| 25 | 20 |

**Source:** Thai Industrial Standard Institute**,** 2533

2.7.6.3 Water absorption

At the time of delivery to the purchaser, units shall conform to the water absorption requirements prescribed in Table 2.9.

**Table 2.9** Water absorption criteria

| Percentage of water absorption (Average of 5 units), Max. % | | |
|---|---|---|
| Average of humidity to year (%) | | |
| < 50 | 50 – 75 | > 75 |
| 25 | 30 | 35 |

**Source:** Thai Industrial Standard Institute**,** 2533

## 2.8 Thermal Conductivity

Thermal conductivity is a property of materials that expresses the heat flux that will flow through the material if a certain temperature gradient exists over the material. It appears primarily in Fourier's Law for heat conduction (Sujan, 1998). First, we define heat conduction by the formula:

$$H = \frac{\Delta Q}{\Delta t} = k \times A \times \frac{\Delta T}{x}$$

Where $\frac{\Delta Q}{\Delta t}$ = the rate of heat flow

$K$ = the thermal conductivity

$A$ = the total cross sectional area of conducting surface

$\Delta T$ = temperature difference

$x$ = the thickness of conducting surface separating the 2 temperatures

Thus, rearranging the equation gives thermal conductivity,

$$k = \frac{\Delta Q}{\Delta t} \times \frac{1}{A} \times \frac{x}{\Delta T}$$

(Note: $\frac{\Delta T}{x}$ is the temperature gradient)

In other words, it is defined as the quantity of heat (ΔQ), transmitted during time (Δ*t*) through a thickness (*x*), in a direction normal to a surface of area (*A*), due to a temperature difference (Δ*T*), under steady state conditions and when the heat transfer is dependent only on the temperature gradient.

Alternatively, it can be thought of as a flux of heat (energy per unit area per unit time) divided by a temperature gradient (temperature difference per unit length)

$$k = \frac{\Delta Q}{A \times \Delta t} \times \frac{x}{\Delta T}$$

Typical units are SI: W/(m·K) and English units: Btu·ft/(h·ft$^2$·°F). To convert between the two, use the relation 1 Btu·ft/(h·ft$^2$·°F) = 1.730735 W/(m·K).

Standard of different methods for thermal conductivity determination of them are summarized in Table 2.10 and the values of thermal conductivity of materials in Table 2.11 and 2.12.

**Table 2.10** Standard methods for thermal conductivity determination

| Method | ASTM Standard | Temperature Range (K) | Suitability | Remarks |
|---|---|---|---|---|
| Axial flow methods (steady-state) | | 90 to 1300 | Homogeneous opaque solids | Most consistent, highest accuracy, Cryogenic temperatures |
| Guarded hot plate method (steady-state) | ASTM C 177 | Extremes of temperatures (high or low) or under vacuum | Insulations | Absolute method of measurement, widely used & versatile |
| Hot wire method (steady-state) | ASTM C1113 | Room temp. to 1773 | Refractories (insulating bricks, Fibrous materials.) | Transient radial flow technique |
| TP02 Nonsteady-state probe | ASTM D 5334-92, D 5930-97 | 243.15 to 453.15 | Suitable in soils | Fast, absolute& sample size is not critical |

**Table 2.11** Values of thermal conductivity of some materials

| Material | Thermal conductivity at 20°C W / mK | Density kg /m3 |
|---|---|---|
| Air | 0.025 | 1.29 |
| Water | 0.6 | 1000 |
| Concrete | 1.28 | 2200 |
| Sand(Dry) | 0.35 | 1600 |
| Sand (Sat.) | 2.7 | 2100 |
| Glass | 0.93 | 2600 |
| Mineral insulation materials | 0.04 | 100 |
| Plastic insulation materials | 0.03 | 50 |

**Table 2.12** Values of thermal conductivity of construction materials

| Material | Thermal conductivity W / mK | Density kg /m3 |
|---|---|---|
| Brick | 1.15 | 1650 |
| Concrete block | 1.3 | 1760 |
| Lightweight concrete | 0.13-0.15 | 550-640 |
| Gypsum board | 0.14-0.19 | 800 |
| Fiber board | 0.21 | 1250-1350 |

**Source:** Department of Alternative Energy Development and Efficiency, Ministry of Energy

## 2.9 Extraction and Leaching Test

As the leachant passes through the sample contaminants are transferred from the stabilized mass to the leachant. This may occur as contaminants are dissolved into the leachant, washed from the surface of the stabilized material, or as contaminants diffuse from within the stabilized mass to the leachant. This, the leachability is depended upon the physical and chemical properties of both the stabilized material and leachant.

Factor affecting leachability

- Surface area of the waste
- Extraction vessel
- Agitation technique and equipment
- Nature of leachant
- Ratio of leachant to waste
- Number of elusions used
- Immersion time
- Temperature
- pH adjustment
- Separation of extract
- Analysis

The extraction procedures for leaching test are divided into two groups – batch (shake) test and column test. For batch test, the samples are continuously contacted with same extract solution in a reaction vessel. For column test, fresh extract solutions are intermittent introduced to contact with a column packed sample (LaGrega MD, 2001).

### 2.9.1 Extraction Procedure Toxicity Test

The Extraction Procedure (EP) Toxicity Test, an old regulatory test being phased out in the Untied States can be used to generate a liquid extract from solid waste. A particular waste is considered to be EP toxic if is extract has concentrations of the eight regulated metals and six pesticides that are greater than the “standard” previously specified in the federal regulations. In this test, the solidified monolithic block is crushed to pass a 9.5-millimeter sieve. A 0.04 < acetic acid (pH = 5) leaching solution is used at a liquid-to-solid ratio of 16:1. The extraction takes place over a period of 24 hour with agitation. The liquid extract is analyzed for specific chemical constituents. For a stabilized mass, the extraction liquid (leachant) is a deionized water acetic acid so the specified pH is archieved. Chemical analyzes of the fitered extract are then conducted to determine the concentration of specified organic and inorganic constituents (LaGrega MD, 2001).

### 2.9.2 Toxicity Characteristics Leaching Procedure (TCLP)

The Toxicity Characteristics Leaching Procedure (TCLP) was adopted on 7$^{th}$ November 1986, by the U.S. EPA under the Hazardous and solid waste amendment of 1984. This regulatory test was adopted as a replacement for the EP Toxicity Test to determine if a particular waste meets the applicable technology – based treatment standard to be land – disposed. The TCLP is also widely used to evaluate the effectiveness of stabilization.

In this test method, the stabilized material is crushed to a particle size smaller than 9.5 millimeters. The crushed material is mixed with a weak acetic acid extraction liquid, in a liquid-to-solid weight ratio of 20:1, and agitated in a rotary extractor for a period of 18 hours at 30 RPM and 22$^{o}$C. After 18 hours of agitation, the sample is filtered through a 0.6 – 0.8 micrometer glass fiber filter and the filtrate is defined as the TCLP extract. This TCLP extract is analyzed for a wide variety of hazardous waste constituents including volatile and semi-volatile organic, metals, and pesticides (LaGrega MD, 2001).

### 2.9.3 Leachate Extraction Procedure based on the announcement of Industrial ministry of Thailand

The Leachate Extraction Procedure was regulated under the Notification of the Ministry of Industry B.E. 2548(2005) issued under the Factory Act, B.E. 2535(1992). There are two option at beginning of the test:

2.9.3.1 If the waste is in the liquid state or solid phase solved in solvent less than 5%, the waste must be filtered through a 0.6 – 0.8 micrometer glass fiber, then operate the leaching test procedure.

2.9.3.2 If there is solid phase more than 5% in the waste, it can be extracted immediately.

The procedure is described as followed;

- Crush the solidified material to pass a 9.5-millimeter sieve.
- Mix 100 g of the sample of with leachant or synthetic acid rain extraction fluid (0.04M sulfuric acid in a mixing ratio of 80:20) at pH 5.0 in a liquid-to-solid weight ratio 20:1.
- Agitate the mixture in the rotary agitator for a period of 18 hours at 30 RPM and 25$^{o}$C.
- Filter the leachate through 0.6 – 0.8 mm. glass fiber filter.
- Conduct the chemical analyses of the filter extract to determine the concentration of specified organic and/or inorganic constituents.

Maximum concentration of heavy metal in leachate issued under the Notification of the Ministry of Industry B.E. 2548(2005) is shown in Table 2.13.

**Table 2.13** Maximum concentration of heavy metals in leachate

| **Contaminants** | **Maximum Concentration (mg/L)** |
|---|---|
| Arsenic (Total) | 5.0 |
| Cadmium (Total) | 1.0 |
| Chromium (Total) | 5.0 |
| Lead (Total) | 5.0 |
| Mercury (Total) | 0.2 |
| Nickel (Total) | 20 |
| Selenium (Total) | 1.0 |
| Silver (Total) | 5.0 |
| Zinc (Total) | 250 |

**Source:** Annoucement of industry Ministry (B.E. 2548)

## 2.10 Related Research

### 2.10.1 Properties of coal fly ash

Narongchai (2543) studied properties of different coal fly ash. It was reported that the different properties of coal fly ash depend on type of coal and temperature of combustion. Also, the shape of fly ash particle has an effect on water for mixing. The spherical and crowded shape of fly ash particle that require the water for mixing more than the edge and spongy shape of fly ash particle, since the water will more replace porosity of these particles.

Waraporn (2536) studied specific gravity of coal fly ash from Maemoh in Thailand. The results showed specific gravity of about 1.90 – 2.30. Also, Kokubu (2538) collected data of specific gravity of coal fly ash from USA, England and Japan, and reported specific gravity of about 2.10 – 2.40. The specific gravity was depended on quantity of $Fe_2O_3$ in fly ash. Thasamat (2543) studied utilization of different fine of fly ash from size separate by Air classifier machine. Their results found the fly ash at more fineness will likely have a specific gravity than fly ash at less fineness. Since the fly ash at high fineness will be less porosity.

Sivasundaram et al. (2533) studied fineness modulus of Sub-bituminous and bituminous fly ash by method of Air Blaine Permeability. Their results found the bituminous fly ash have a fineness modulus more than Sub-bituminous fly ash. When replacement cement at 20% and 30% found that the bituminous fly ash has compressive strength more than Sub-bituminous fly ash, since the bituminous fly ash have a fineness modulus more than Sub-bituminous fly ash.

### 2.10.2 Element in coal fly ash

Brigden et al. (2002) studied toxic elements in fly ashes collection from the Mae Moh and Thai petrochemical industry coal – fired power plants in Thailand. The coal fly ash from Mae Moh is lignite fly ash. The coal fly ash from Thai Petrochemical Industry is bituminous fly ash. The results of concentration of heavy metal from both sites are shown bellow in Table 2.14.

**Table 2.14** Concentration of elements identified in sample of fly ash from the Mae Moh and Thai Petrochemical Industry (TPI) coal power plants

| Element | Concentration of heavy metal mg/kg (dry weight) | |
|---|---|---|
| | Mae Moh | TPI |
| Arsenic | 172 | 18 |
| Cadmium | <1 | <1 |
| Calcium | 108604 | 12729 |
| Chromium | 39 | 52 |
| Cobalt | 16 | 37 |
| Copper | 52 | 26 |
| Lead | 22 | 14 |
| Manganese | 566 | 307 |
| Mercury | 8.8 | 1.2 |
| Nickel | 36 | 160 |
| Zinc | 156 | 217 |

The concentrations of elements detected in the two fly ash samples are within a similar range to concentrations reported for fly ashes from similar facilities in other countries. It is shown bellow in Table 2.15

**Table 2.15** Summary of reported element composition of fly ashes from similar coal fired power facilities

| Element | Concentration of heavy metal (mg/kg (dry weight)) | | | |
|---|---|---|---|---|
| | 4 coal power plants, Greece | 1050 MW coal power plants, Spain | 11 coal power plants, UK | Coal fly ash, China |
| | Fytianos and Tsaniklidi, 1998 | Lorens et al., 2001 | Wadge et al., 1986 | Liao and Jiang, 1999 |
| Arsenic | n/r | 60 | 40 – 205 | n/r |
| Cadmium | 11.6 – 14.4 | 1.3 | 0.13 – 0.82 | 312 – 315 |
| Calcium | n/r | 39700 | n/r | n/r |
| Chromium | 110 – 160 | 134.2 | n/r | n/r |
| Cobalt | n/r | 29.2 | n/r | n/r |
| Copper | 31.8 – 62.8 | 71.8 | n/r | n/r |
| Lead | 123 – 143 | 52.0 | 17 – 176 | 843 – 847 |
| Manganese | 213 – 330 | 324.6 | n/r | n/r |
| Mercury | n/r | 0.01 | n/r | 8.1 – 8.3 |
| Nickel | n/r | 87.9 | n/r | n/r |
| Zinc | 59.6 – 86.9 | 221.3 | n/r | n/r |

**Remark:** n/r indicates that no data were reported

### 2.10.3 Effect of fly ash on the compressive strength

Parinya and Intrachai (2528) studied the compressive strength of lignite fly ash mix with cement. It was reported that the compressive strength will be decrease when lignite fly ash portion increase. However, the compressive strength will be increased when curing time increases. The appropriate of replacement cement were in the range 0 – 40 % (by weight).

Supakij and Sitipon (2536) studied the compressive strength of lignite fly ash in concrete from Mae Moh. They found the compressive strength related to lignite fly ash proportion and curing time. The percentage of replacement cement to maximum compressive strength is 10 – 30 and 10 – 20 for design of compressive strength of 210 $kg/cm^2$ and 250 $kg/cm^2$ respectively.

### 2.10.4 Utilization of fly ash

Tarun et al. (1990) studied workability and setting characteristics of high-fly ash content concretes using a Class C fly ash. Mixture proportions were developed for concrete by maintaining a fly ash-to-cement replacement ratio of 1.25. For control mixtures without fly ash, water-cementitious materials ratios of 0.45, 0.55, and 0.65 were used. Their results showed that addition of fly ash in concrete mixtures increased workability and decreased water demand. For a constant workability, the water-cementitious materials ratio decreased substantially when the level of cement replacement by fly ash was increased from zero to 60 %. The results further indicated that the initial and final set times were not significantly affected for cement replacements by Class C fly ash in the range of 35 to 55 % for all the concrete mixtures tested in the investigation.

Ghosh and Timusk (1981) evaluated strength properties of concrete containing Class C fly ash. Concrete mixtures were proportioned for strength levels of 21, 35 and 55 MPa. The effect of high carbon content of fly ash (6 to 18 percent as measured by LOI), fly ash-to-cement plus fly ash ratio (16.7 %, 28.6 %, and 50 %), and fineness of fly ash, on the concrete performance was studied. Test data showed slightly lower early age compressive strength for fly ash concrete relative to the reference concrete containing no fly ash. However, at later ages, except for 55 MPa concrete, fly ash concrete showed higher compressive strength compared to the reference concrete without fly ash.

Cuijuan et al. (1986) determined the effects of dosage of a calcium-enriched Class F fly ash on strength development of concrete. The test results showed that concrete, with less than 25 % fly ash as a replacement of cement, attained higher compressive strength compared to the no-fly ash concrete. At 40 percent cement replacement with the fly ash, concrete either exceeded or approached the strength levels indicated by the no- fly ash concrete, at both 90 and 180-day ages.

Naik et al. (1995) determined mechanical properties of paving concrete incorporating both Class C and Class F fly ash for cement replacements in the range of 20 to 50 %. A 40 % Class F fly ash mixture with a superplasticizer was also used. The water-cementitious materials ratio ranged between 0.34 - 0.40 for the Class C fly ash mixtures. All mixtures contained 353 kg/m3 of cement plus fly ash. Test results showed compressive strength at 28 days in excess of design strength of 24 MPa for all of the Class C fly ash mixtures (20 and 50 % cement replacements), while it was 24 MPa for the 40 % Class F fly ash mixtures. The average splitting tensile strength was found to vary from 2.3 to 3.4 MPa at 28 days and from 3.0 to 3.7 MPa at 56 days. This study showed average flexural strength for mixtures tested varying from 4.0 to 4.7 MPa at 28 days, 4.4 to 4.9 MPa at 56 days, and 5.2 to 6.3 MPa at 128 days.

Siddique (2003) presents the results of an experimental investigation carried out to evaluate the mechanical properties of concrete mixtures in which fine aggregate was partially replaced with Class F fly ash. Fine aggregate was replaced with five percentages (10%, 20%, 30%, 40% and 50%) of Class F fly ash by weight. Tests were performed for properties of fresh concrete. Compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity were detected at 7, 14, 28, 56, 91 and 365 days. Test results indicate significant improvement in the strength properties of plain concrete by the inclusion of fly ash as partial replacement of fine aggregate, and can be effectively used in structural fly ash concrete.

Tarun et. al (2003) provides the state-of-the-art information on high-calcium, ASTM Class C fly ash used in cement-based construction materials, such as high-performance concrete, ready mixed concrete, and low-strength flowable concrete and slurry. The major topics included are properties of fly ash; effects of fly ash inclusion on properties of fresh and hardened concrete and controlled low-strength materials and future research needs. The fresh concrete properties discussed are workability, water requirement, bleeding, segregation, air content, time of setting, and temperature rise. The hardened concrete properties such as compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, creep and shrinkage, permeability, carbonation and corrosion of steel in concrete, abrasion resistance, freezing and thawing resistance, salt-scaling resistance, alkali- silica reaction, sulfate resistance, and fatigue strength are described. The results show that high-strength/high-durability /high-performance concrete containing significant amounts (up to 75 % cement replacement levels) of Class C fly ash can be manufactured for strength levels of up to 100 MPa.

Freidin and Erell (1994) determined the volume mass, compressive strength, water uptake and water absorption of pressed test samples made of a mixture of coal &ash, slag and sodium silicate solution. It was found that such mixtures can solidify in the open air and form water-stable materials. The composition and structure of new formations for the binder and cured material itself were established using X-ray diffraction and a scanning electron microscope. The material has a high water uptake, which may be reduced using a number of different methods, the best of which is short-term impregnation with a hydrophobic material of the siloxane group. The water uptake and water absorption of compressed samples impregnated with such materials are similar to those of comparable building materials, such as lime-sand bricks, clay bricks or concrete blocks.

Ramazan (2006) studied the effect of silica fume (SF), class C fly ash (FA), blast furnace slag (BFS), SF+FA, SF+BFS, and FA+BFS on the thermal conductivity (TC); and compressive strength of concrete were investigated. Density decreased with the replacement of mineral admixtures at all levels of replacements. The maximum TC of 1.233W/mK was observed with the samples containing plain cement. It decreased with the increase of SF, FA, BFS, SF+FA, SF+BFS, and FA+BFS. The maximum reduction was, 23%, observed at 30% FA. Compressive strength decreased with 3-day curing period for all mineral admixtures and at all levels of replacements. However, with increasing of curing period reductions decreased and for 7.5% SF, 15% SF, 15% BFS, 7.5% SF+7.5% FA, 7.5% SF+7.5% BFS replacement levels compressive strength increased at 28 days, 7- and 28-days, 120 days, 28- and 120 days, 28 days curing periods, respectively. Maximum compressive strength was observed at 15% BFS replacement at curing period of 120 days.

Tsong et al. (2005) studied the abrasion–erosion resistance of high-strength concrete mixtures in which cement was partially replaced by four kinds of replacements (15%, 20%, 25% and 30%) of class F fly ash. The mixtures containing ordinary Portland cement were designed to have 28 days compressive strength of approximately 40–80 MPa. The results show that the abrasion–erosion resistances of fly ash concrete mixtures were improved by increasing compressive strength and decreasing the ratio of water-to-cementitious materials. The abrasion–erosion resistance of concrete with cement replacement up to 15% was comparable to that of control concrete without fly ash. Beyond 15% cement replacement, fly ash concrete showed lower resistance to abrasion–erosion compared to non-fly ash concrete. Equations were established based on effective compressive strengths and effective water-to-cementitious materials ratios, which were modified by cement replacement and developed to predict the 28- and 91-day abrasion–erosion resistance of concretes with compressive strengths ranging from approximately 30–100 MPa. The calculation results are compared favorably with the experimental results.

Pipat et al. (2005) studied the effect of water curing condition on compressive strengths of fly ash–cement paste by quantitative data of hydration degree. The result shows that the hydration degree of belite is affected by water curing conditions, more so than that of fly ash and alite. Fly ash still continues to hydrate even without an extra, external supply of water. The strong dependence of fly ash–cement concrete on curing conditions does not come from the hydration degree of fly ash, but rather comes from the hydration degree of cement, especially belite. When the water to binder ratio is low enough, the hydration of cement plus small hydration of fly ash are considered to be enough for adequate compressive strength at the beginning. Then, compressive strength of fly ash–cement paste becomes less sensitive to the water curing period.

Metta (2004) studied the dye-adsorbed fly ash on its pozzolanic property in terms of compressive strength by using it as a partial substitute to Portland cement type I to produce mortar. The result revealed that the highest compressive strength was of the sample containing 10% by weight of the dye-adsorbed fly ash in replacement of cement. It possessed 215 kg/cm2 at 28 days, which is 92.67% of the sample containing 10% by weight of the original fly ash in replacement of cement, or 83.33 of the cement mortar. For the environmental concern, leachabilities of lead (Pb), chromium (Cr), copper (Cu) and zinc (Zn) from all mortars were also carried out. No leaching of the heavy metals from any samples could be detected. Hence, the dye-adsorbed fly ash can be used as an environmental friendly construction material.

Bundit (2003) studied about utilizing unground rice husk ash for producing hollow non-load bearing concrete block. Two types of rice husk ash, black rice husk ash from electrical generating power plant and black rice husk ash from rice mill, were used. The percentage replacements of rice husk ash in aggregate (limestone crushing rock) by weight were 0%, 10%, 15%, and 20%. The tested results showed that the compressive strength of rice husk ash concrete block increased when the percentage replacements of rice husk ash in aggregate increased and was also higher than the minimum specified value from TIS 58-2530 standards, whereas the unit weight of rice husk ash concrete block decreased.

# CHAPTER III
# MATERIALS AND METHODS

## 3.1 Research Design

This study was an experimental research, and was carried out to determine the chemical and physical properties of bituminous fly ash. The experimental study was divided into 2 phases as follows:

**Phase I: Study of mixing proportion**

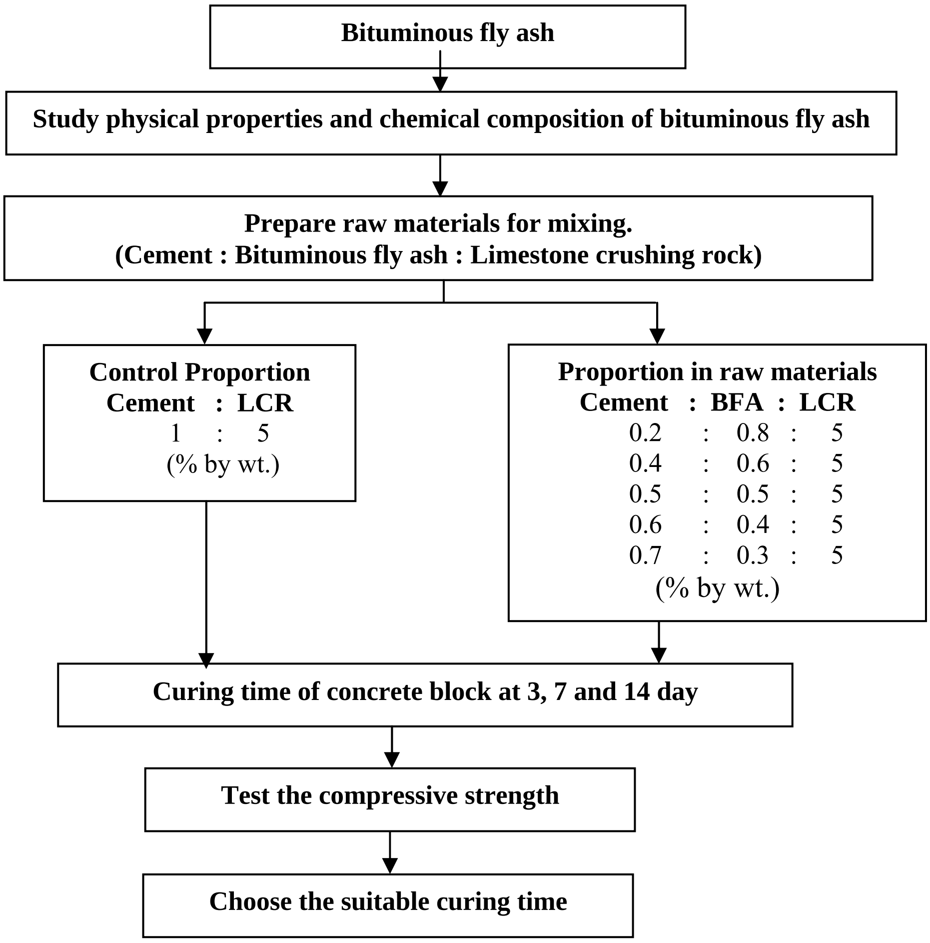
This phase was to study the different mixing proportions of bituminous fly ash, cement and limestone crushing rock for hollow concrete block product. Then, optimum curing time will be chosen to determine its compressive strength.

**Phase II: Study the properties and unit cost of the hollow concrete block product**

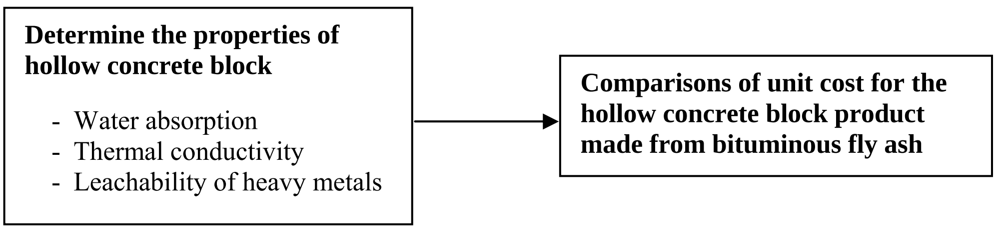
This phase was carried out after knowing suitable curing time. All mixing proportions of hollow concrete blocks were tested for the properties of water absorption, thermal conductivity and leachability of heavy metals. Finally, the unit cost for hollow concrete blocks product was analyzed.

## 3.2 Experimental Frameworks

**Phase I Study of mixing proportion**




**Phase II: Study the properties and unit cost of the hollow concrete block product.**




**Remark :** BFA = Bituminous fly ash
LCR = limestone crushing rock

**Figure 3.1** Experimental frameworks

## 3.3 Materials

### 3.3.1 Bituminous fly ash

The bituminous fly ashes were obtained from bituminous coal-fired for fuel in Samut Prakarn textile factory.

### 3.3.2 Portland Cement

The ordinary Portland cement type 1 was according to ASTM C 150 (elephant brand).

### 3.3.2 Aggregate

The limestone crushing rock was aggregate. The particle size distribution was in accordance with the TIS 566 - 2528.

### 3.3.4 Mixing water

The ordinary tap water supplied was used for all concrete mixes.

## 3.4 Equipment

### 3.4.1 Equipment for hollow concrete blocks production includes:

1) Concrete making machine
2) Concrete mixer
3) Coarse scale
4) Shovel
5) Pond for curing hollow concrete blocks

### 3.4.2 Equipment for testing hollow concrete blocks includes:

1) Equipment for the compressive strength test
   - Universal Testing Machine (UTM)

2) Equipment for the water absorption test
- Fine scale
- Oven
- Bucket

3) Equipment for the thermal conductivity test
- Hot plate
- Cold Plate
- Thermal conductivity analyzer
- Thermocouple

4) Equipment for the leachability test
- Sieve No. 3/8 in.
- Analytical balance
- Plastic bottle
- Flasks 250 ml
- Rotary extractor
- Pipette
- Filter paper No. 42
- pH meter
- Atomic Absorption Spectrophotometer

## 3.5 Parameters and Analytical Methods

### 3.5.1 The properties of bituminous fly ashes

The properties of bituminous fly ash were analyzed in parameter of chemical composition, particle characteristics and surface image, fineness modulus, specific gravity and concentration of heavy metal. The properties of bituminous fly ash were important for properties of hollow concrete block from replacement cement by bituminous fly ash. The analytical method of properties of bituminous fly ash was shown in Table 3.1.

**Table 3.1** Parameters for testing the physical properties and chemical composition of bituminous fly ash

| Parameters | Analytical Methods |
|---|---|
| Chemical composition | X – Ray Fluorescence Spectrometer. |
| Particle characteristics and surface image | Scanning Electron Microscope |
| Fineness modulus | Sieve No.325 |
| Specific gravity | ASTM C 128 – 07 |
| Concentration of heavy metal Cr, As, Ni and Zn | Atomic Absorption Spectrophotometer |

**3.5.2 The physical property of limestone crushing rock**

The physical property of limestone crushing rock was analyzed in parameter of particle size distribution. The particle size distributions of limestone crushing rock are important for workability of forming and compressive strength of hollow concrete block. The analytical method of particle size distributions was shown in Table 3.2.

**Table 3.2** Parameters for testing the limestone crushing rock

| Parameters | Analytical Method |
|---|---|
| Particle size distribution | TIS 566-2528 |

**3.5.3 The physical and mechanical properties of hollow concrete block product**

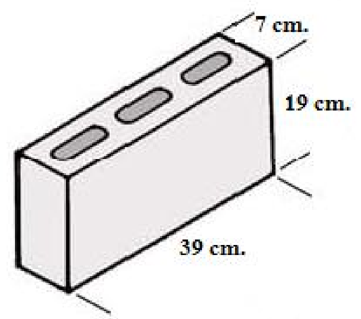
This part focuses on the properties of hollow concrete block from replacement cement by bituminous fly ashes, which was compared with the standard of hollow concrete block included compressive strength (curing time at 3, 7, and 14 day) and water absorption. The parameters for testing the properties of hollow concrete blocks were shown in Table 3.3.

**Table 3.3** The parameters for testing the properties of hollow concrete blocks

| Parameters | Analytical Methods |
|---|---|
| Compressive strength | TIS 109-2517 |
| Water absorption | TIS 109-2517 |
| Thermal conductivity | ASTM D5334<br>Hot wire probe |
| Leachability of heavy metals<br>Cr, As, Ni and Zn | Waste extraction test<br>Atomic Absorption Spectrophotometer |

## 3.6 Production of hollow Concrete blocks

Hollow Concrete blocks or non-load-bearing concrete masonry units were produced from mixing proportion of cement, aggregate and water. Thereafter, it was brought into concrete making machine. The shape of hollow concrete is shown in Figure.3.2




**Main block**

**Size 7 × 19 × 39 cm**

**Weight average 7 kg**

**Figure 3.2** Shape of main hollow concrete block

### 3.6.1 Preparation of raw material

The sample was consisted of raw material including cement, limestone crushing rock and water. The ratio of cement and limestone crushing rock were 1:5 by weight (Wanchai, 1988). The calculation was based on using 8 kg of hollow concrete block as raw material for one piece. So, 25 pieces of hollow concrete blocks will use

200 kg of raw material (8 x 25). The proportion of raw material from replacement cement by bituminous fly ash is shown in Table 3.4.

**Table 3.4** Proportion of replacement the cement in hollow concrete block production

| No. | Replacement the cement by bituminous fly ash (% by weight) | W/B Ratio | Ratio of mixer BFA : Cement : LCR | Proportion of mixture (Kg.) | | | Number of piece |
|---|---|---|---|---|---|---|---|
| | | | | BFA | Cement | LCR | |
| 1 | 0 | 0.5 | 0 : 1 : 5 | 0 | 33.3 | 166.7 | 25 |
| 2 | 20 | 0.6 | 0.2 : 0.8 : 5 | 6.7 | 26.6 | 166.7 | 25 |
| 3 | 40 | 0.65 | 0.4 : 0.6 : 5 | 13.3 | 20 | 166.7 | 25 |
| 4 | 50 | 0.65 | 0.5 : 0.5 : 5 | 16.7 | 16.7 | 166.7 | 25 |
| 5 | 60 | 0.7 | 0.6 : 0.4 : 5 | 20 | 13.3 | 166.7 | 25 |
| 6 | 70 | 0.7 | 0.7 : 0.3 : 5 | 23.3 | 10 | 166.7 | 25 |
| Total | | | | 80 | 120 | 1000 | 150 |

W/B : Water to Binder (Cement + BFA) ratio

BFA : Bituminous fly ash

LCR : limestone crushing rock

### 3.6.2 Procedure for hollow concrete blocks production

3.6.2.1 Weigh the bituminous fly ash, cement and limestone crushing rock as shown in Table 3.4.

3.6.2.2 The bituminous fly ash, cement and limestone crushing rock were mixed in concrete mixer. This step was shown in Figure 3.3.

3.6.2.3 The mixing water was added into the concrete mixer. This step was shown in Figure 3.4.

3.6.2.4 When the mixture was mixed completely, it would be placed into concrete making machine for hollow concrete block product in mold size 7×19×39cm. This step was shown in Figure 3.5.

3.6.2.5 The hollow concrete blocks were stored indoor for air dry for 3 days. This step was shown in Figure 3.6.


**Figure 3.3** Mixture mixed in concrete mixer


**Figure 3.4** Water added into the concrete mixer


**Figure 3.5** Making the hollow concrete block

**Figure 3.6** Dried the hollow concrete block

### 3.6.3 Procedure for curing hollow concrete blocks

3.6.3.1 The hollow concrete blocks were taken to be completely covered with sack.

3.6.3.2 Cure all the time with water for damp.

3.6.3.3 The period of curing time for 3, 7 and 14 day. This step was shown in Figure 3.7.

3.6.3.4 The hollow concrete block products were taken to test as outlined in 3.7.


**Figure 3.7** Curing the hollow concrete block

There was no specific of curing time for hollow concrete block. Therefore, in this study, the curing time for hollow concrete block was the one specified by reference from the curing time of general concrete structure (Sedthabut. (1996). The curing times selected were 3, 7 and 14 day for Portland cement. The most suitable curing time was, then, selected from these three curing times.

## 3.7 Analytical Procedure

### 3.7.1 Procedure for testing compressive strength

3.7.1.1 Measure cross section and weigh hollow concrete block

3.7.1.2 The hollow concrete block was put into the Universal Testing Machine.

3.7.1.3 Record the value of compressive strength from testing.

3.7.1.4 Calculate the compressive strength of the hollow concrete block as follows.

$$fc' = P/A$$

When $fc'$ = compressive strength (Kg/ $cm^2$)

$P$ = Pressure (Kg)

$A$ = Cross section area ($cm^2$)

### 3.7.2 Procedure for test of water absorption

3.7.2.1 The hollow concrete blocks were brought to dry in the oven at 100 – 110 ºC for 24 hr. Thereafter it was air dried at room temperature about 4 hours. Then, the weight was recorded.

3.7.2.2 The hollow concrete blocks were immersed in water for 24 hours. Then, bring it out to weigh.

3.7.2.3 Calculate the water absorption of the hollow concrete blocks as follows.

$$\text{Weight of water absorption} = A - B$$

$$\text{Water absorption (\%)} = \frac{A - B}{B} \times 100$$

When A = saturated weight of specimen (kg)

B = oven-dry weight of specimen (kg)

### 3.7.3 Procedure for test of thermal conductivity

3.7.3.1 Measure the cross section and thickness of hollow concrete block.

3.7.3.2 The hollow concrete block was placed on the hot plate for thermal conductivity analysis.

3.7.3.3 Measure the temperature difference between the top surface and the bottom surface of the hollow concrete block by thermocouple.

3.7.3.4 Record the value of thermal conductivity analyzer.

3.7.3.5 Calculate the thermal conductivity (k) of the hollow concrete block as follows.

$$k = \frac{\Delta Q}{A \times \Delta t} \times \frac{x}{\Delta T}$$

When k = thermal conductivity (Watt/mater/kelvin)

$\Delta Q$ = quantity of heat (Watt)

$\Delta t$ = during time of transmitted (Second)

A = the cross sectional area of hollow concrete block ($m^2$)

$\Delta T$ = temperature difference (kelvin)

$x$ = the thickness of hollow concrete block (meter)

### 3.7.4 Procedure for leachability test

3.7.4.1 Prepare the solid portion of the waste for extraction by crushing, cutting, or grinding the waste to finest size as possible. It must pass through a 9.5 mm standard sieve.

3.7.4.2 Add 50 g of crushed samples into a Polyethylene Plastic bottle.

3.7.4.3 Prepare extraction leachant which was 0.2 M of sodium critrate at pH of 5±0.2.

3.7.4.4 Add the extraction leachant of 500 ml into extractor bottle (a Polyethylene Plastic bottle that have sample).

3.7.4.5 Extract of oxygen from extractor bottle at 15 minute by nitrogen gas.

3.7.4.6 The bottles were shaken on the rotary extractor, which is operated at 48 hours at room temperature.

3.7.4.7 Separate the leachate with filter paper No. 42

3.7.4.8 After that, bring 100 ml. of sample to add 2 ml. of nitric acid and 5 ml. of hydrochloric acid.

3.7.4.9 Bring sample to digest on hot plate at 90 – 95 $^{o}$C until 15 – 20 ml. of sample remains. Dilute the sample for 100 ml. with distilled water.

3.7.4.10 After that, analyze the leaching of heavy metal by using atomic absorption spectrophotometer.

## 3.8 The analysis of unit cost for hollow concrete block product

In this phase, the optimum ratio of bituminous fly ash to Portland cement was selected to replace cement by bituminous fly ash to make hollow concrete block. Thereafter, calculation would be done to find out all cost of hollow concrete block production from replacing cement by bituminous fly ash. Comparison would be determined for all cost of hollow concrete block production from a small factory located in Kanchanaburi province.

**Scope of analysis**

1) The analysis considering of productivity cost includes :
    - Material cost
    - Labor cost
    - Electricity cost
    - Wear cost
2) The analysis did not include the cost of bituminous fly ash and freight cost.

## 3.9 Laboratory facilities

3.9.1 The physical properties and chemical composition of bituminous fly ash were tested at the central laboratory of Chulalongkorn University.

3.9.2 The hollow concrete blocks were produced at a small construction materials factory, Thamaka, Kanchanaburi province.

3.9.3 The properties of sample were tested at the laboratory of Department of Civil Engineering, Faculty of Engineering, Mahidol University.

3.9.4 The leachability test was operated at the laboratory of Sanitary Engineering Department, Faculty of Public Health, Mahidol University.

# CHAPTER IV
# RESULT AND DISCUSSION

This research aimed to investigate the potential use of bituminous fly ashes as cement replacement to produce hollow concrete block. The bituminous fly ashes were brought to analyze for chemical and physical properties. The experiment was conducted replacing Portland cement with bituminous fly ash between 0 – 70 percent by weight. Curing times were 3, 7 and 14 days. This product was referred to Thai Industrial Standard Institute for hollow non-load-bearing concrete masonry units under TIS 58-2533. This product was brought to analyze for hollow concrete block properties according to the TIS 109-2517 standard method. Its properties included compressive strength and water absorption. Moreover, its thermal conductivity was analyzed according to the ASTM D5334-05 standard method. The hollow concrete block was also measured the leaching of heavy metal according to the Annoucement of Industry Ministry (B.E. 2548). Finally, the unit cost for hollow concrete blocks product was analyzed.

## 4.1 The physical and chemical properties of bituminous fly ash

### 4.1.1 The physical properties

The bituminous fly ashes were collected from bituminous coal fire process of textile factory in Samut Prakarn province. It was analyzed for physical properties including specific gravity and fineness by sieve No.325. The results of physical properties were shown in Table 4.1.

**Table 4.1** The physical properties of bituminous fly ash and cement Portland type I

| The physical properties | Bituminous fly ash | Cement Portland type I |
|---|---|---|
| Specific gravity [1] | 2.25 | 3.15 |
| Fineness [2]<br>Retained on Sieve No. 325 (%) | 39% | 5.7% |

**Remark:** [1] The specific gravity was concerned to the ASTM C128-04a (Standard Test Method for Specific Gravity and Absorption of Fine Aggregate)

[2] The fineness was concerned to the ASTM C430-96 (Standard Test Method for Fineness of Hydraulic Cement by the 45-μm (No. 325) Sieve) The standard was specified retained on No.325 (sieve not more than 34%).

Specific gravity of bituminous fly ash and cement Portland type 1 were 2.25 and 3.15 respectively. The specific gravity of bituminous fly ash is less than specific gravity value of cement Portland type 1. So, the density of particle of bituminous fly ash is less than that of cement particle Portland type 1. As a result, hollow concrete block from replacement cement by bituminous fly ash is lighter than hollow concrete block from cement only.

Result of fineness test showed that the weight of bituminous fly ash and cement Portland type 1 particles was retained on sieve No. 325 of 39 and 5 percent respectively. It showed that the particles of bituminous fly ashes were larger than particles of cement Portland type 1. The fineness of bituminous fly ashes was retained on sieve No. 325 slightly more than that of the standard requirement which must not be greater than 34 percent. This was one of the reasons for considering bituminous fly ashes as a non – pozzolan. The comparison of pozzolan properties for bituminous fly ashes was shown in Table 4.3.

The particle size and surface image of Portland cement and bituminous fly ash were observed by Scanning Electron Microscope (SEM) with magnification of x 500. Microstructure of Portland cement and bituminous fly ash were shown in Figure 4.1 and 4.2.

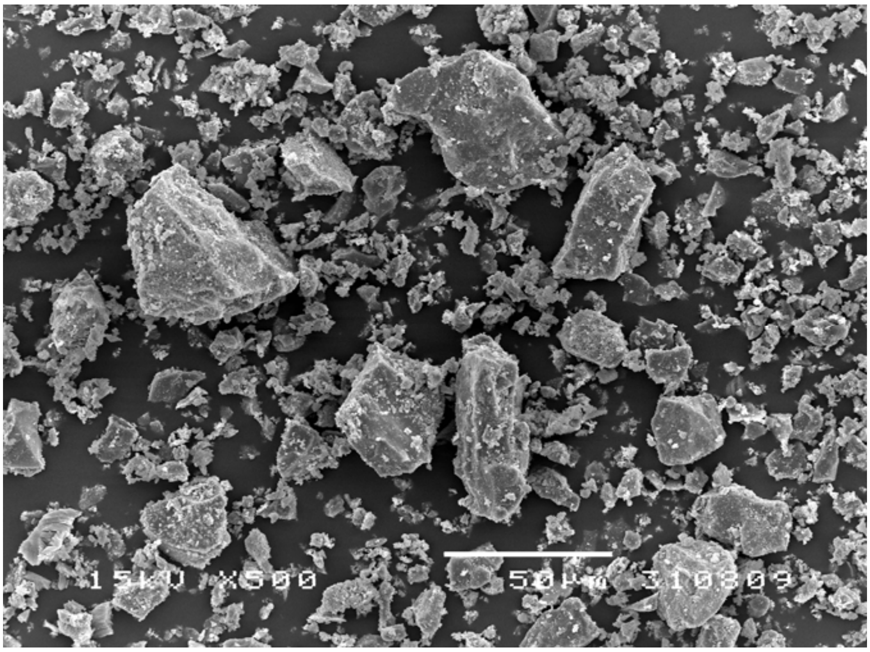



**Figure 4.1** Microstructure of Portland cement with magnification of x 500

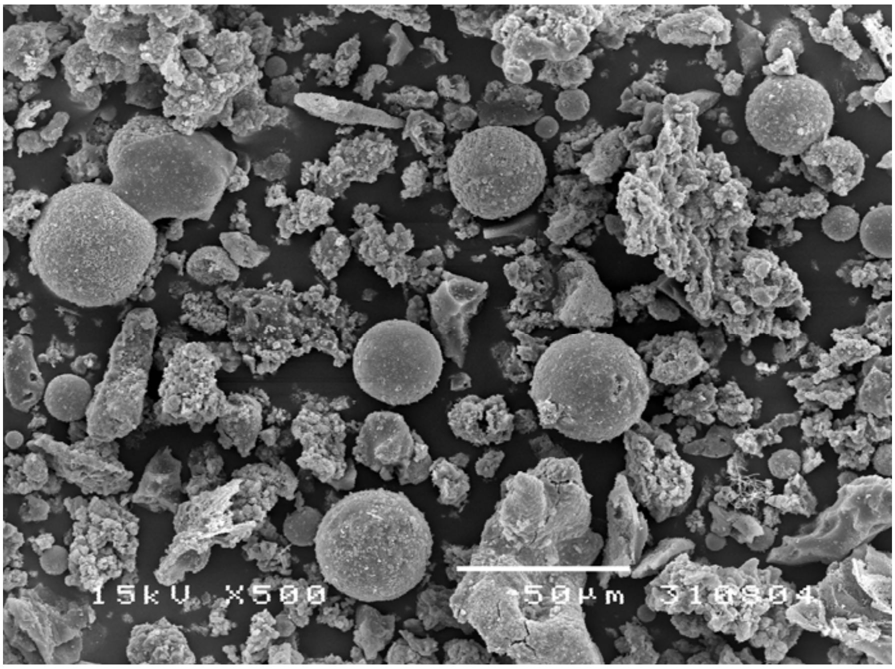



**Figure 4.2** Microstructure of bituminous fly ash with magnification of x 500

Figure 4.1 showed that Portland cement appearance is non-uniform. Cement particle size is in the range of 10 – 50 micrometers. Its surface is rough. Figure 4.2 showed that the size of bituminous fly ash were rather larger than Portland cement. Bituminous fly ash particles size were in the range of 20 – 70 micrometers. Its texture presenting bituminous fly ash particles consisted of heterogeneous particles and many types such as spherical, edge and spongy shape. The interesting part of this bituminous fly ash is about its porosity. Its texture is close to spongy.

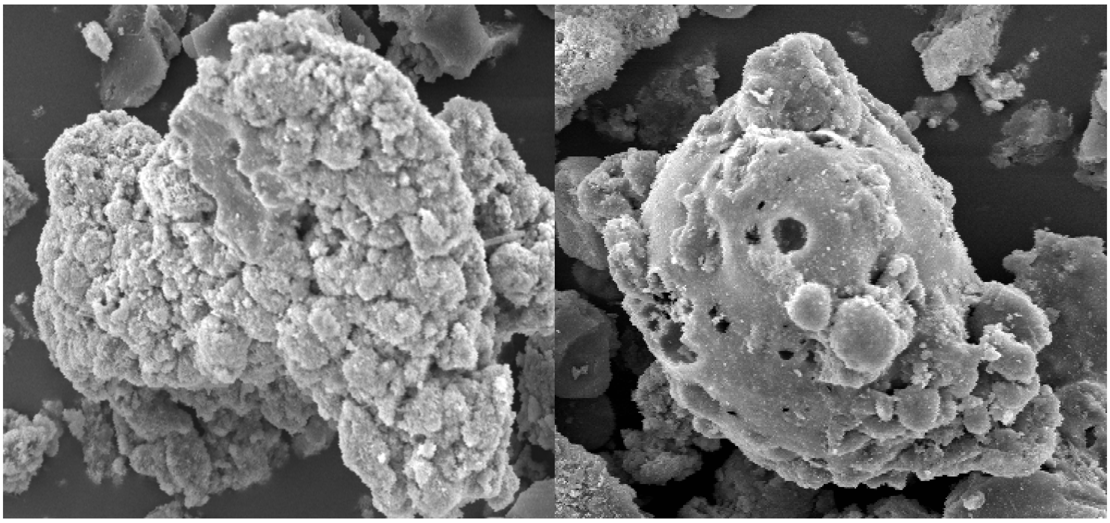


**Figure 4.3** Microstructure of spongy shape.

Figure 4.3, shows the spongy shape of bituminous fly ash particle. It has more porosity surface area. This property has an effect on loss of compressive strength when it replaced Portland cement. Also, the water will replace porosity of these particles. Result of experiment showed the compatibility that more replacement of bituminous fly ash for Portland cement occurred, more water is needed for mixing in hollow concrete block production.

### 4.1.2 The chemical compositions

Chemical composition of bituminous fly ash was analyzed by X-ray fluorescence spectrometer. Comparison with cement Portland type 1 were shown in Table 4.2.

**Table 4.2** The chemical compositions of bituminous fly ash and cement Portland type I

| Chemical compositions | Bituminous fly ash | Cement Portland Type I |
|---|---|---|
| Silicon Dioxide ($SiO_2$) | 17.4 | 20.93 |
| Aluminum Oxide ($Al_2O_3$) | 5.28 | 4.76 |
| Iron oxide ($Fe_2O_3$) | 20.81 | 3.48 |
| Calcium oxide (CaO) | 28.29 | 65.42 |
| Magnesium oxide (MgO) | 8.33 | 1.25 |
| Sodium oxide ($Na_2O$) | 0.13 | 0.20 |
| Potassium Oxide ($K_2O$) | 0.27 | 0.32 |
| sulfur trioxide ($SO_3$) | 1.15 | 2.74 |

Table 4.2 showed the chemical composition of bituminous fly ash. The result showed that chemical composition of Silicon Dioxide, Aluminum Oxide, Iron oxide and Calcium oxide were the main oxides. Oxide in bituminous fly ash consisting of Silicon Dioxide, Aluminum Oxide, Iron oxide and Calcium oxide were detected at the percentages of 17.4, 5.28, 20.81 and 28.29 respectively. Oxide in cement Portland type 1 were detected at the percentages of 20.93, 4.76, 3.48 and 65.42 respectively.

The standard of pozzolan in accordance with ASTM C618-94a (Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for use as a Mineral Admixture in Concrete) was specified the summation of total amounts of $SiO_2$, $Al_2O_3$, and $Fe_2O_3$ in Class F and Class C fly ash not less than 70 and 50 percent respectively. The total amounts of $SiO_2$, $Al_2O_3$, and $Fe_2O_3$ in bituminous fly ash were 43.49 %. The comparison of pozzolan properties were shown in Table 4.3.

**Table 4.3** The comparison of pozzolan properties

| **Properties Requirement** | | | |
|---|---|---|---|
| **Chemical Properties** | Fly Ash Class | | Bituminous fly ash |
| | F | C | |
| Silicon dioxide, Aluminum oxide, Iron oxide ($SiO_2$ + $Al_2O_3$ + $Fe_2O_3$) min. % | 70 | 50 | 43.49 |
| Sulfur trioxide ($SO_3$), max. % | 5.0 | 5.0 | 1.15 |
| **Physical properties** | | | |
| Fineness, max. % retained on 325-mesh sieve | 34 | 34 | 39 |

The result showed that the values of physical and chemical properties were less than those values specified by ASTM 618-08. So, the bituminous fly ash in this research was not identified as pozzolan in accordance with ASTM C618-08. Thus, the bituminous fly ash in this study was inert substance, and was not binding when mixed with cement. These results did not agree with the first hypotheses. When the replacement for cement increases, it results in the decrease of compressive strength of the hollow concrete block. So, the bituminous fly ashes acted like replacement materials for limestone crushing rock more than Portland cement.

### 4.1.3 The concentration of heavy metal

Bituminous fly ash was analyzed for heavy metals including Arsenic, Lead, Chromium, Nickel and Zinc in form of total concentration (mg/kg) by Atomic absorption spectrophotometer. The concentration of heavy metals was shown in Table 4.4.

**Table 4.4** Concentration of heavy metal

| **Parameter** | **concentration of heavy metal (mg/kg)** | | | |
|---|---|---|---|---|
| | **As (total)** | **Cr (total)** | **Ni (total)** | **Zn (total)** |
| Bituminous fly ash | ND | 14.25 | 97.15 | 21.85 |
| TTLC | 500 | 2500 | 2000 | 5000 |

TTLC = Total Threshold Limit Concentration (Annoucement of industry Ministry (B.E. 2548))

ND = Not Detect (limit of measurement heavy metal concentration of AAS = 0.001 mg/L)

Table 4.4 shows the concentrations of heavy metals in bituminous fly ash. All parameters in this study were below the standard (Total Threshold Limit Concentration). So, the bituminous fly ash from textile factory in Samut Prakarn province does not potentially pose adverse effect to the environment.

## 4.2 The particle size distribution of limestone crushing rock

The particle size distribution of limestone crushing rock was analyzed using sieve size No. 4 – 100 (following the standard method for concrete block aggregates from Thai Industrial Standard No. TIS 566 – 2528). The particle size distribution were shown in Table 4.5.

**Table 4.5** The particle size distribution of limestone crushing rock

| Size of Sieve | Percent pass through on sieve of limestone crushing rock | Standard of percent pass through on sieve |
|---|---|---|
| 4.75 – mm. (No.4) | 100 | 90 – 100 |
| 2.36 – mm. (No.8) | 77.3 | 75 – 100 |
| 1.18 – mm. (No.16) | 59.3 | 55 – 90 |
| 600 – µm (No. 30) | 38 | 35 – 59 |
| 300 – µm (No. 50) | 21 | 8 – 30 |
| 150 – µm (No. 100) | 10.3 | 0 – 20 |

Table 4.5 and Figure 4.4 showed the particle size distribution of limestone crushing rock in this study. The results appeared to be appropriate for particle size distribution of limestone crushing rock. The particle size distribution of limestone crushing rock were within the range requirement of standard for concrete aggregates (Thai Industrial Standard No. TIS 566 – 2528). The particle size distributions of limestone crushing rock from large to small size are continuous, indicating the suitable workability of the hollow concrete block. So, the limestone crushing rock that used in this study were appropriate to apply in hollow concrete block production.

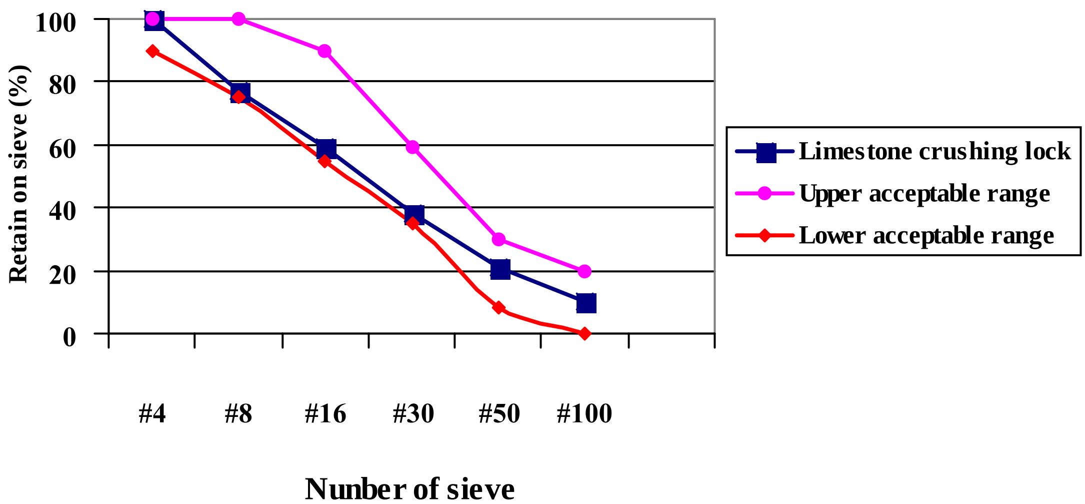



**Figure 4.4** The particle size distributions of limestone crushing rock

## 4.3 The characteristics of hollow concrete block product

The hollow concrete block product from the replacement of cement by bituminous fly ash in this research has the size of 7 × 19 × 39 cm. It follows standard of Thai Industrial Standard No. TIS 58-2533 (Referenced from ASTM C129 Standard Specification of hollow non-load-bearing concrete masonry units). It is shown in Figure 4.5.

**Figure 4.5** Shape of hollow concrete block product.

### 4.3.1 The compressive strength

In this study bituminous fly ash replaced cement at 0%, 20%, 40%, 50%, 60% and 70% respectively by weight. It mixed in the hollow concrete blocks and used the water to cement ratio of 0.5, 0.6, 0.65 and 0.7. After shape forming, these hollow concrete blocks were cured at 3, 7 and 14 days.

Procedure to test compressive strength of hollow concrete block product followed the Thai Industrial Standard No. TIS 109 – 2517 (Referenced from ASTM C140 Standard Method of Sampling and Testing Concrete Masonry Units). Results of compressive strength at curing time of 3, 7 and 14 day were shown in Table 4.6, 4.7 and 4.8 respectively.

**Table 4.6** Compressive strength of hollow concrete blocks at curing time of 3 days

| Conditions | Weight | Compressive strength (kg/cm$^2$) | | | |
|---|---|---|---|---|---|
| | | Min | Max | Mean | S.D. |
| Control | 7.20 | 128.3 | 136.0 | 133.2 | 3.102 |
| 20% | 7.12 | 114.4 | 120.7 | 116.6 | 2.468 |
| 40% | 7.05 | 87.1 | 96.2 | 91.1 | 3.590 |
| 50% | 6.93 | 77.0 | 90.8 | 85.0 | 5.026 |
| 60% | 6.81 | 61.8 | 70.4 | 66.5 | 3.301 |
| 70% | 6.60 | 28.1 | 36.8 | 32.1 | 3.287 |

**Table 4.7** Compressive strength of hollow concrete blocks at curing time of 7 days

| Conditions | Weight | Compressive strength (kg/cm$^2$) | | | |
|---|---|---|---|---|---|
| | | Min | Max | Mean | S.D. |
| Control | 7.21 | 147.0 | 153.5 | 150.0 | 2.314 |
| 20% | 7.14 | 123.4 | 130.1 | 127.9 | 2.653 |
| 40% | 7.10 | 102.0 | 112.9 | 107.2 | 4.175 |
| 50% | 7.03 | 92.2 | 97.5 | 94.9 | 1.924 |
| 60% | 6.90 | 75.5 | 83.0 | 79.7 | 2.819 |
| 70% | 6.71 | 40.9 | 47.0 | 45.0 | 2.545 |

**Table 4.8** Compressive strength of hollow concrete blocks at curing time of 14 days

| Conditions | Weight | Compressive strength (kg/cm$^2$) | | | |
|---|---|---|---|---|---|
| | | Min | Max | Mean | S.D. |
| Control | 7.25 | 150.1 | 155.7 | 152.5 | 2.294 |
| 20% | 7.18 | 128.1 | 135.5 | 132.6 | 2.785 |
| 40% | 7.14 | 113.8 | 117.7 | 114.4 | 3.303 |
| 50% | 7.05 | 97.2 | 105.0 | 100.8 | 3.025 |
| 60% | 6.94 | 76.0 | 86.7 | 83.2 | 4.309 |
| 70% | 6.75 | 46.8 | 52.5 | 50.3 | 2.183 |

**Remark :** Standard of Thai Industrial Standard No. TIS 58-2533 that requirement should be more than 25 kg/cm$^2$

The mean compressive strength value for the 3-day curing time decreased when the replacement of Portland cement by bituminous fly ash increased in all portions. Mean value of compressive strength of control unit was 133.2 kg/cm$^2$. The greatest compressive strength of hollow concrete blocks was observed at the proportion of bituminous fly ash of 20%, the mean compressive strength was 116.6 kg/cm$^2$ and the compressive strength decreased 12% when compared to compressive strength of control unit. The least compressive strength of hollow concrete blocks was noticed at the portion of bituminous fly ash of 70%, the mean compressive strength was 32.1 kg/cm$^2$; and the compressive strength decreased 76% when compared to that of the control unit.

The mean compressive strength value for 7-day curing time decreased when the replacement of Portland cement by bituminous fly ash increased in all portion. The mean compressive strength of control unit was 150.0 kg/cm$^2$. The greatest compressive strength of hollow concrete blocks was observed at the proportion of bituminous fly ash of 20%, the mean compressive strength was 127.9 kg/cm$^2$ and the compressive strength decreased 15% when compared to compressive strength of control unit. The least compressive strength of hollow concrete blocks was noticed at the portion of bituminous fly ash of 70%, the mean compressive strength was 45.0 kg/cm$^2$; and the compressive strength decreased 70% when compared to that of the control unit.

The mean compressive strength value for 14-day curing time decreased when the replacement of Portland cement by bituminous fly ash increased in all portion. The mean compressive strength of control unit was 152.5 kg/cm$^2$. The greatest compressive strength of hollow concrete blocks was observed at the proportion of bituminous fly ash of 20%, the mean compressive strength was 132.6 kg/cm$^2$ and the compressive strength decreased 13% when compared to compressive strength of control unit. The least compressive strength of hollow concrete blocks was noticed at the portion of bituminous fly ash of 70%, the mean compressive strength was 50.3 kg/cm$^2$; and the compressive strength decreased 67% when compared to that of the control unit.

Statistical analysis "ANOVA" was employed to test the effect of bituminous fly ash on the compressive strength due to the normal distribution of dependent variable. The statistical analysis at P-value of < 0.05 demonstrated that there was an effect from bituminous fly ash proportion on compressive strength. The Least-Significant Different (LSD) multiple comparisons procedure was used to compare means of pair groups, when means of at least two groups were significantly different and variance was equal for each population. The Pearson Correlation is commonly used for parametric measure of correlation between two variables.

The results of the mean of compressive strength on different bituminous fly ash proportion were shown in Table 4.9; there was a statistical difference of compressive strength at 3 days curing time (P-value < 0.001), 7 days curing time (P-value < 0.001) and 14 days curing time (P-value < 0.001) . So, the follow-up tests were conducted to evaluate pairwise differences among the mean. From results (Table B-1, B-2 and B-3 in appendix B), the multiple comparisons showed that the mean of compressive strength at bituminous fly ash all proportion were statistically different in all curing times (P-value < 0.001).

**Table 4.9** The result of ANOVA statistical analysis for the compressive strength on different bituminous fly ash proportions in curing time 3, 7 and 14 days.

| Curing time | Bituminous fly ash proportion | Mean (kg/cm$^2$) | S.D. | ANOVA | |
|---|---|---|---|---|---|
| | | | | F-test | P-value |
| 3 days | 0 | 133.2 | 3.102 | 512.31 | < 0.001 |
| | 20 | 116.6 | 2.468 | | |
| | 40 | 91.1 | 3.590 | | |
| | 50 | 85.0 | 5.026 | | |
| | 60 | 66.5 | 3.301 | | |
| | 70 | 32.1 | 3.287 | | |
| 7 days | 0 | 150.0 | 2.314 | 850.22 | < 0.001 |
| | 20 | 127.9 | 2.653 | | |
| | 40 | 107.2 | 4.175 | | |
| | 50 | 94.9 | 1.924 | | |
| | 60 | 79.7 | 2.819 | | |
| | 70 | 45.0 | 2.545 | | |
| 14 days | 0 | 152.5 | 2.294 | 699.77 | < 0.001 |
| | 20 | 132.6 | 2.785 | | |
| | 40 | 114.4 | 3.303 | | |
| | 50 | 100.8 | 3.025 | | |
| | 60 | 83.2 | 4.309 | | |
| | 70 | 50.3 | 2.183 | | |

The results of correlation analyses (Table B-1, B-2 and B-3 in Appendix) demonstrated that the correlation between bituminous fly ash proportion and the compressive strength at 3 days curing time was significant, r = -0.959 (P-value < 0.001). The results showed that it was highly inversely correlated between the bituminous fly ash proportion and the compressive strength. That means, when bituminous fly ash proportion increased, the compressive strength will be decreased. At 7 days curing time, the correlation between bituminous fly ash proportion and the compressive strength was significant, r = -0.968 (P-value < 0.001). The results showed that it is highly inversely correlated between the bituminous fly ash proportion and the compressive strength. That means, when bituminous fly ash proportion increased, the compressive strength will be decreased. And at 14 days curing time, the correlation between bituminous fly ash proportion and the compressive strength was significant, r = -0.962 (P-value < 0.001). The results showed that it is highly inversely correlated between the bituminous fly ash proportion and the compressive strength. That means, when bituminous fly ash proportion increased, the compressive strength will be decreased.

The results of the mean of compressive strength on curing time were shown in Table 4.10; there was not a statistical difference of compressive strength (P-value = 0.104).

**Table 4.10** The result of ANOVA statistical analysis for the compressive strength on curing time.

| Curing time (days) | Mean ($kg/cm^2$) | S.D. | ANOVA | |
|---|---|---|---|---|
| | | | F-test | P-value |
| 3 | 87.4 | 33.509 | 2.236 | 0.104 |
| 7 | 100.8 | 34.320 | | |
| 14 | 105.6 | 33.796 | | |

The results of correlation analyses (Table B-4 in Appendix) demonstrated that the correlation between curing time and the compressive strength was significant, r = 0.206, (P-value = 0.026). The result indicated that it was slightly positively correlated between the curing time and the compressive strength. That means, when the curing time increased, the compressive strength will be increased.

### Stepwise Regression Analysis of Compressive Strength

The result of stepwise regression analysis (Table B-5 in Appendix) showed that the effect of bituminous fly ash proportions and curing time proportion on the compressive strength. That means, 88.7% of bituminous fly ash proportions have influence to change compressive strength and 4.2% of curing time have influence to change compressive strength. From the result, it was indicated that bituminous fly ash proportions had more effect than curing time on compressive strength. The compressive strength could be predicted using a linear combination of bituminous fly ash proportions, curing time (P-value < 0.001) as follows:

$$Y = 139.481 - (1.348 \times X1) + (1.547 \times X2)$$

$(R^2 = 0.923)$

When Y = Compressive strength (kg/cm$^2$)

X1 = Bituminous fly ash proportion (%)

X2 = Curing time (days)

**Remark :** The prediction was within the limit of condition that bituminous fly ash proportion (X1) at 0 – 70 % and curing time (X2) at 3 – 14 days.

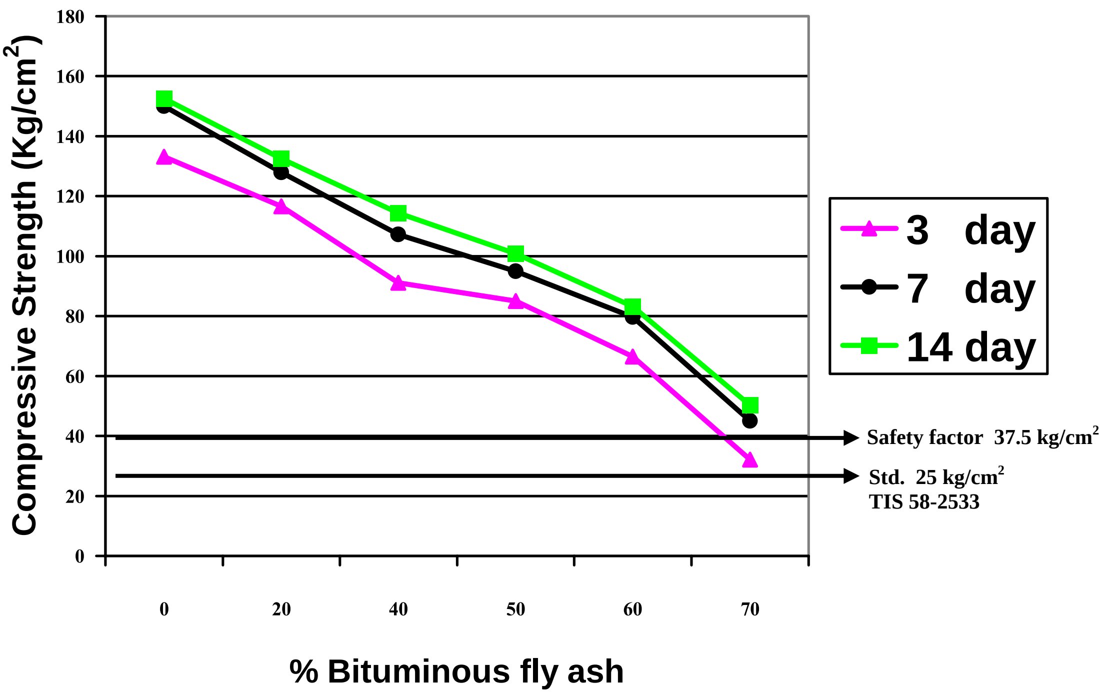



**Figure 4.6** The compressive strength of hollow concrete block in different bituminous fly ash proportions at 3, 7 and 14 days curing time.

One of the possible reasons could be the non-pozzolan property of the bituminous fly ash as identified by the ASTM 618-08 in Table 4.3. Thus, it was an inert substance, and was not binding when mixed with cement. In this regard, it acted like replacement materials for limestone crushing rock rather than Portland cement. Another explanation was the spongy shape of the bituminous fly ash, as shown in Figure 4.3, that may have an effect on compressive strength reduction. The water replacing porosity during the mixing process resulted in voids in hollow concrete block, hence, reducing the compressive strength

The longer curing time resulted in the compressive strength of hollow concrete block in all proportions increased. When curing time was increased, so was the hydration and pozzolanic reaction (reaction between CaO with water and CaO with $SiO_2$). This was due to the hydration and pozzolanic reaction as described by equation mentioned in chapter 2. From the equation, $SiO_2$ reacted with calcium oxide and converted to calcium silicate. The combination of calcium silicate and water turned to calcium silicate hydrate, which improved cementitious function between molecular structures and age hardening of concrete, rendering the increase of compressive strength of hollow concrete block. However, its compressive strength in maximum proportion of bituminous fly ash at 70% from all curing time was acceptable when compared to the Thai Industrial Standard No. TIS 58-2533. The required compressive strength should be more than 25 kg/cm$^2$. It was shown in Figure 4.6.

The graph in Figure 4.6 showed that compressive strength of hollow concrete block increased as the curing time was longer: 3, 7 and 14 days, accordingly. The percentages of increasing rate of average compressive strength in the range of curing time from 3 days to 7 days and 7 days to 14 days were 15.28 and 4.81 respectively. The compressive strength in maximum proportion (70%) of replacement Portland cement by bituminous fly ash at curing time of 3, 7 and 14 days were 32.1, 45.0 and 50.3 kg/cm$^2$, respectively. The suitable curing time was selected based on safety factor of compressive strength. The safety factor of compressive strength was specified not less than 37.5 kg/cm$^2$ (25 x 1.5), which was 1.5 times of the standard compressive strength according to the TIS 58-2533 (not less than 25 kg/cm$^2$). The compressive strength in maximum proportion (70%) of replacement Portland cement by bituminous fly ash at curing time of 3 days was less than 37.5 kg/cm$^2$ of safety factor; whereas, at curing time of 7 and 14 days, it was more than 37.5 kg/cm$^2$ of safety factor. Moreover, the curing time of 14 days would be a waste of time. Therefore, the suitable curing time was chosen at 7 days in producing hollow concrete.

### 4.3.2 The water absorption

In this study, bituminous fly ash replaced cement 0%, 20%, 40%, 50%, 60% and 70% by weight. It mixed in the hollow concrete blocks using the water to cement ratio of 0.5, 0.6, 0.65 and 0.7. After forming shape, these concrete blocks were cured for 7 days.

The procedure of testing water absorption of hollow concrete block product followed the Thai Industrial Standard No. TIS 109 – 2517 (Referenced from ASTM C140 Standard Method of Sampling and Testing Concrete Masonry Units). The water absorption was shown in Table 4.11.

**Table 4.11** Water absorption of hollow concrete blocks at curing time of 7 days

| Conditions | Water absorption (%) | | | |
|---|---|---|---|---|
| | Min | Max | Mean | S.D. |
| Control | 6.2 | 7.4 | 6.8 | 0.503 |
| 20% | 6.4 | 8.1 | 7.3 | 0.619 |
| 40% | 8.0 | 10.8 | 9.7 | 1.250 |
| 50% | 10.2 | 11.4 | 10.7 | 0.559 |
| 60% | 11.8 | 12.8 | 12.3 | 0.356 |
| 70% | 13.2 | 15.6 | 14.5 | 0.971 |

**Remark :** The Thai Industrial Standard No. TIS 58-2533 requires that water absorption should be less than 25%.

The mean value water absorption for curing time 7 days increased when the replacement of Portland cement by bituminous fly ash increased in all proportions. The mean water absorption of control unit was 6.8 %. The least water absorption of hollow concrete blocks was 7.3% occurring at the proportion of bituminous fly ash of 20%. The greatest water absorption of hollow concrete blocks was 14.5% occurring at the proportion of bituminous fly ash of 70%.

The statistical analysis “ANOVA” was employed to test whether bituminous fly ash had an effect on the water absorption, because the dependent variable was normally distributed. The statistical analysis at P-value of < 0.05 demonstrated that there was an effect from bituminous fly ash proportion on water absorption. Least-Significant Different (LSD) multiple comparisons procedure was used to compare means of pair groups, when means at least two groups were significantly different and variance was equal for each population. The Pearson Correlation is commonly used for parametric measure of correlation between two variables.

The results of the mean of water absorption on different bituminous fly ash proportion were shown in Table 4.12; it indicated that there was a statistical difference of water absorption at 7 days curing time (P-value < 0.001). So, the follow-up tests were conducted to evaluate pairwise differences among the means. From the results (Table B-6 in appendix B), the multiple comparisons showed that the means of water absorption at all proportions of bituminous fly ash at curing time of 7 days were statistically different (P-value < 0.05).

**Table 4.12** The result of ANOVA statistical analysis for the water absorption on different bituminous fly ash proportions at 7 days curing time

| Curing time | Bituminous fly ash proportion | Mean (%) | S.D. | ANOVA | |
|---|---|---|---|---|---|
| | | | | F-test | P-value |
| 7 days | 0 | 6.8 | 0.503 | 74.34 | < 0.001 |
| | 20 | 7.3 | 0.619 | | |
| | 40 | 9.7 | 1.250 | | |
| | 50 | 10.7 | 0.559 | | |
| | 60 | 12.3 | 0.356 | | |
| | 70 | 14.5 | 0.971 | | |

The results of correlation analyses (Table B-6 in appendix B) demonstrated that the correlation between bituminous fly ash proportion and the water absorption at 7 days curing time was significant, r = 0.934 (P-value < 0.001). The results showed that it was highly positively correlated between the bituminous fly ash proportion and the water absorption; that means, when bituminous fly ash proportion increases, the water absorption will be increased.

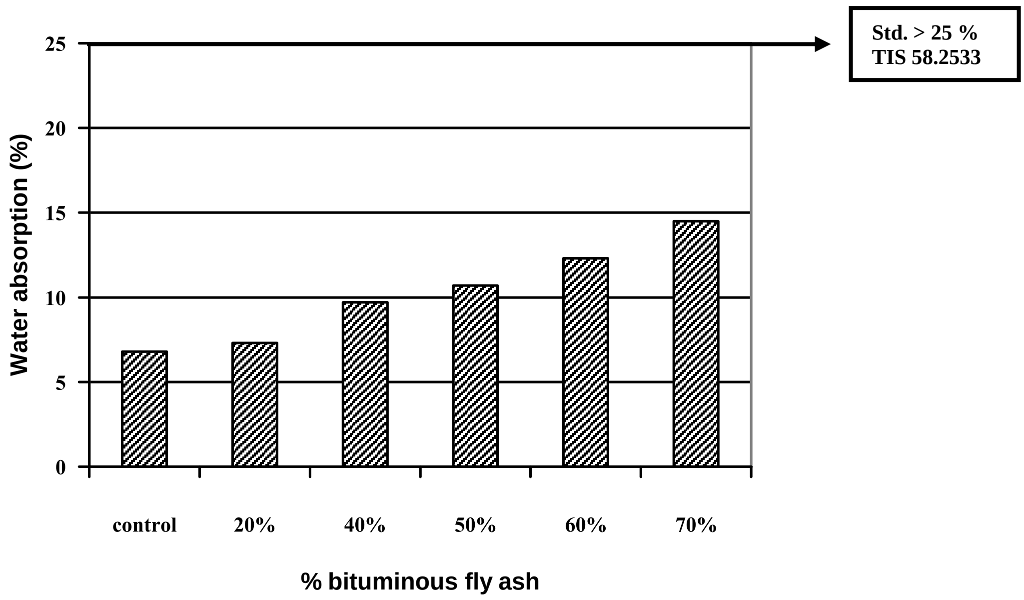



**Figure 4.7** The water absorption of hollow concrete block in different bituminous fly ash proportions

Figure 4.7 showed that water absorption of hollow concrete block will be increased when fly ash replacement for Portland cement increased (Water absorption varied directly with fly ash replacement). This phenomena induced hollow concrete block to increase water absorption. These results agree with the fourth hypothesis which states that the water absorption of hollow concrete block increased as the proportion of bituminous fly ash increased.

Bituminous fly ash surface is rough; and it is porous in shape, so, water molecule is able to pass its porosity easily. Results showed more water absorption due to its high porosity. Its texture was analyzed by Scanning Electron Microscope as shown in Figure 4.2. However water absorption of maximum proportion of bituminous fly ash at 70% is allowed when compared to the Thai Industrial Standard No. TIS 58-2533. The requirement of compressive strength should be less than 25 %.

### 4.3.3 The thermal conductivity

The thermal conductivity of hollow concrete block in this study used the standard of non steady state by hot wire probe method according to ASTM D 5334-05 (Method for Determination of Thermal Conductivity of Soil and Soft Rock). Units of thermal conductivity are W/m.k (watt per metre kelvin).

The thermal conductivity of hollow concrete block from replacement cement by bituminous fly ash for 0%, 20%, 40%, 50%, 60% and 70% were tested at the curing time of 7 days. The results of thermal conductivity from all proportion were shown in Table 4.13 and Figure 4.8.

**Table 4.13** Thermal conductivity of hollow concrete block at curing time of 7 days

| Conditions | Thermal conductivity (W/m.k) | | | |
|---|---|---|---|---|
| | Min | Max | Mean | S.D. |
| Control | 1.5353 | 1.5413 | 1.5372 | 0.002 |
| 20% | 1.5128 | 1.5217 | 1.5183 | 0.004 |
| 40% | 1.4778 | 1.5110 | 1.4883 | 0.013 |
| 50% | 1.4761 | 1.5135 | 1.4919 | 0.017 |
| 60% | 1.4779 | 1.5023 | 1.4872 | 0.009 |
| 70% | 1.4280 | 1.4280 | 1.4714 | 0.026 |

Table 4.13 and Figure 4.8 showed the results of thermal conductivity of hollow concrete block. The mean thermal conductivity was about 1.4-1.5 W/m.k. The mean thermal conductivity was decreased when the replacement cement by bituminous fly ash increased. The means thermal conductivity in the hollow concrete block made from bituminous fly ash (replacement cement by bituminous fly ash of 20%, 40%, 50%, 60% and 70%) were 1.5183, 1.4883, 1.4919, 1.4872 and 1.4714 W/m.k respectively. The control unit (0% of bituminous fly ash) had the highest thermal conductivity as 1.5372 W/m.k; whereas the maximum proportion (70% bituminous fly ash) had the lowest thermal conductivity as 1.4714 W/m.k.

The statistical analysis “ANOVA” was employed to test whether bituminous fly ash had an effect on the thermal conductivity, because the dependent variable was normally distributed. The statistical analysis at P-value of $< 0.05$ demonstrated that there was an effect from bituminous fly ash proportion on thermal conductivity. Least-Significant Different (LSD) multiple comparisons procedure was used to compare means of pair groups, when means at least two groups were significantly different and variance was equal for each population. The Pearson Correlation is commonly used for parametric measure of correlation between two variables.

The results of the mean of thermal conductivity on different bituminous fly ash proportion were shown in Table 4.14; there was a statistical difference of thermal conductivity at 7 days curing time (P-value < 0.001). So, the follow-up tests were conducted to evaluate pairwise differences among the means. From the results (Table B-7 in appendix B), the multiple comparisons showed that the means of thermal conductivity at bituminous fly ash all proportion at curing time of 7 days were statistically different (P-value < 0.05).

**Table 4.14** The result of ANOVA statistical analysis for the thermal conductivity on different bituminous fly ash proportions in curing time of 7 days

| Thermal conductivity | Bituminous fly ash proportion | Mean (W/m.k) | S.D. | ANOVA | |
|---|---|---|---|---|---|
| | | | | F-test | P-value |
| 7 days | 0 | 1.5372 | 0.002 | 13.85 | < 0.001 |
| | 20 | 1.5183 | 0.004 | | |
| | 40 | 1.4883 | 0.013 | | |
| | 50 | 1.4919 | 0.017 | | |
| | 60 | 1.4872 | 0.009 | | |
| | 70 | 1.4714 | 0.026 | | |

The results of correlation analyses (Table B-7 in appendix B) demonstrated that the correlation between bituminous fly ash proportion and the thermal conductivity at 7 days curing time was significant, r = -0.837 (P-value < 0.001). The results showed that it was highly inversely correlated between the bituminous fly ash proportion and the thermal conductivity; that means, when bituminous fly ash proportion increases, the thermal conductivity will be decreased.

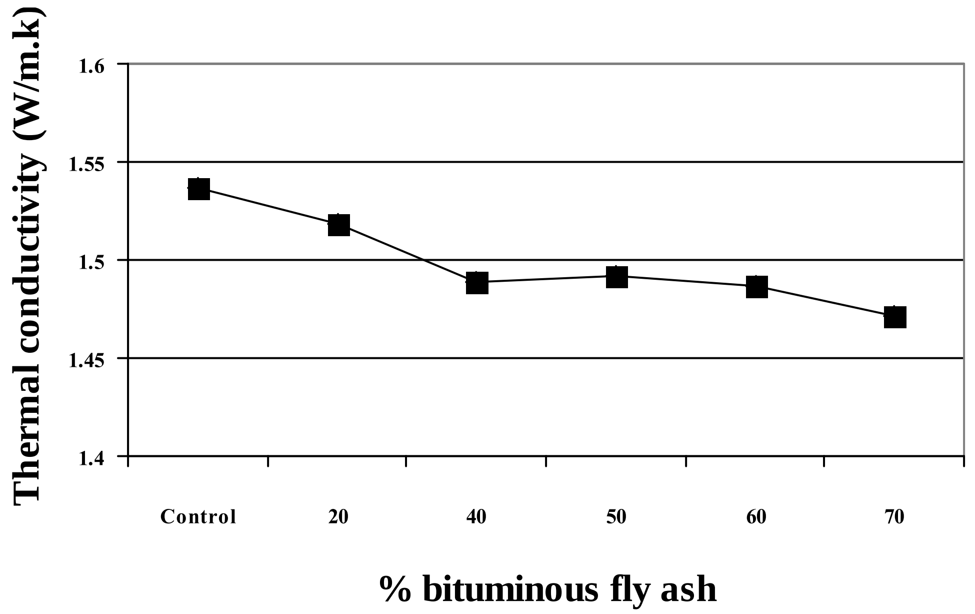



**Figure 4.8** The thermal conductivity of hollow concrete block in different bituminous fly ash proportions

From this study, it was found that the hollow concrete blocks have higher value of thermal conductivity when compared with that of other construction materials from the Table 2.12 (in literature reviews). Since the hollow concrete block was hard material with compress and crowded molecules, thus, making the transmission of heat from side to side of hollow concrete block was excellent. Generally, the material that has lower thermal conductivity will be better for heat protection (Sujan, 1998).

The result of thermal conductivity test showed that thermal conductivity value decreased when ratio between cement and bituminous fly ash increased which corresponded to the fifth hypothesis. The reason could be that bituminous fly ash has lower specific gravity than Portland cement; in addition, its particle shape looked like spongy and high porosity. Thus, when more volume of bituminous fly ash replaced volume of Portland cement, the weight of hollow concrete block would be lighter (Molecule of hollow concrete block would be less compressed and porosity, therefore, it should be lighter). This results in the decrease of heat transfer from one side to the other. So, thermal conductivity of hollow concrete block will be decreased when bituminous fly ash replacement increased.

A room was constructed with hollow concrete block as wall materials in order to demonstrate that the thermal conductivity of hollow concrete block can reduce temperature in the room. Then, comparison was made of different temperature between hollow concrete block from replacement cement by bituminous fly ash at 0% and 70% with thermal conductivity between 1.5372 and 1.4714 (W/m.k), respectively. Calculation was made for the rate of heat flow to inside room and the temperature that decreased. The formula for this study was shown as follows (Preeya, 1991).

$$H = \frac{kA\,(T_2 - T_1)}{L}$$

When
- $H$ = Rate of heat flow (Watt)
- $k$ = Thermal conductivity (W/m.k)
- $A$ = Cross sectional area of room ($m^2$)
- $T_1$ = Inside room temperature (°C)
- $T_2$ = Outside room temperature (°C)
- $L$ = Thickness of hollow concrete block (m)

The first step was the calculation for rate of heat flow (H) into the room. Calculation for control unit (hollow concrete block from replacement cement by bituminous fly ash at 0%) was assumed at the room area (A) of 5 $m^2$ and outside room temperature ($T_2$) of 30 °C and inside room temperature ($T_1$) of 25 °C. The thermal conductivity was 1.5372 W/m.k. The thickness of hollow concrete block was 0.07 m. This calculation is shown as follows.

$$H = \frac{(1.5372)\,(5)\,(30 - 25)}{0.07} = 549 \text{ Watt}$$

The second step was the calculation for the temperature inside the room ($T_1$) that decreased from using hollow concrete block from replacement cement by bituminous fly ash at 70% for room wall. The rate of heat flow (H) was 549 Watt. The thermal conductivity was 1.4714 W/m.k. The thickness of hollow concrete block was

0.07 m. Assuming the room area (A) of 5 $m^2$ and outside room temperature ($T_2$) of 30 °C, the calculation is shown as follows.

$$549 = \frac{(1.4714)\,(5)\,(30 - T_1)}{0.07}$$

$$\frac{(549)\,(0.07)}{(1.4714)\,(5)} = 30 - T_1$$

$$T_1 = 30 - 5.2$$

$$T_1 = 24.8 \ °C$$

From the calculation for different temperature between hollow concrete block from replacement cement by bituminous fly ash at 0% and 70%. The result showed that the temperature inside the room was 24.8 °C when using hollow concrete block from replacement cement by bituminous fly ash at 70%. The temperature was decreased from the control unit 0.2 °C (The temperature inside the room of control unit was 25 °C).

Although the usage of hollow concrete block from replacement cement by bituminous fly ash at 70% could reduce the temperature inside the room, only slightly decreased. If it needs to be used for protecting heat, further study should be developed.

### 4.3.4 The result of leachability test

The heavy metals tested for leaching out of hollow concrete block at proportions of bituminous fly ash of 0%, 20%, 40%, 50%, 60% and 70% included Arsenic, Chromium, Nickel and Zinc. The leachability test was performed using Atomic absorption spectrophotometer. The concentrations of heavy metals leached out of the hollow concrete block at all proportions bituminous fly ash are demonstrated in Table 4.15 and Figure 4.9.

**Table 4.15** Concentrations of leached heavy metals from hollow concrete block

| Conditions | Concentrations of heavy metals (mg/l) | | | |
|---|---|---|---|---|
| | Cr | Zn | Ni | As |
| Control | 0.295 | 0.157 | 0.467 | ND |
| 20% | 0.323 | 0.237 | 0.515 | ND |
| 40% | 0.343 | 0.198 | 0.603 | ND |
| 50% | 0.327 | 0.261 | 0.641 | ND |
| 60% | 0.257 | 0.213 | 0.590 | ND |
| 70% | 0.191 | 0.209 | 0.660 | ND |
| Standard (STLC) | 5 | 250 | 20 | 5 |

STLC = Soluble Threshold Limit Concentration (Annoucement of industry Ministry (B.E. 2548))

ND = Not Detect (limit of measurement heavy metal concentration of AAS = 0.001 mg/L)

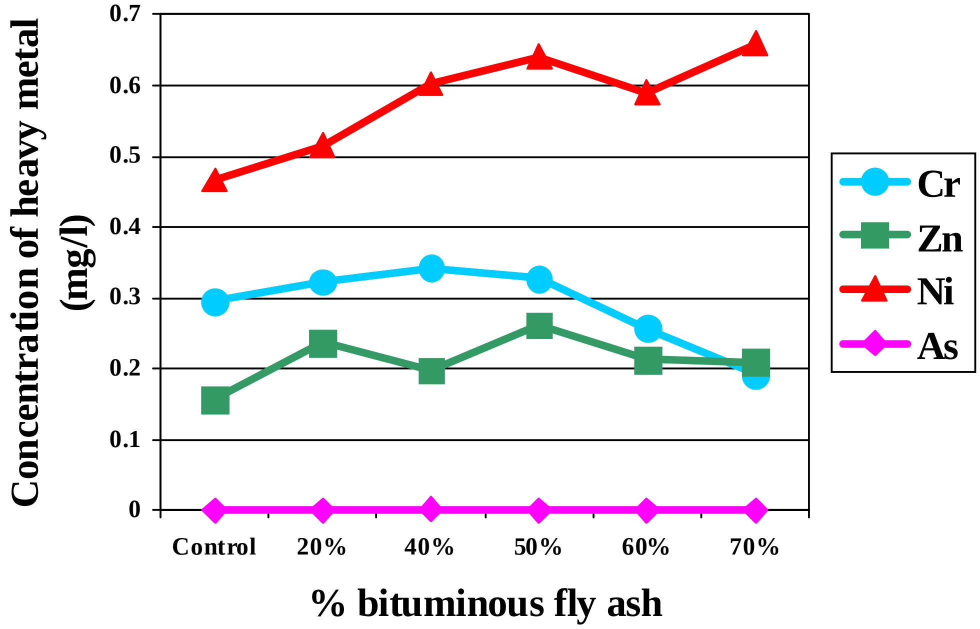



**Figure 4.9** Concentration of leached heavy metals from hollow concrete block at different bituminous fly ash proportions

The statistical analysis "ANOVA" was employed to test whether bituminous fly ash had an effect on the leaching of heavy metals, because the dependent variable was normally distributed. The statistical analysis at P-value of < 0.05 demonstrated that there was an effect of bituminous fly ash proportion on the leaching of heavy metals. The Pearson Correlation is commonly used for parametric measure of correlation between two variables. The ANOVA result of the detected heavy metals in Table 4.16 can be explained below.

**Table 4.16** The result of ANOVA statistical analysis for the leachability of heavy metals at different bituminous fly ash proportions

| Parameter | Bituminous fly ash Proportion (%) | Mean (mg/l) | S.D. | ANOVA | |
|---|---|---|---|---|---|
| | | | | F-test | P-value |
| Cr | 0 | 0.295 | 0.031 | 1.3248 | 0.310 |
| | 20 | 0.323 | 0.064 | | |
| | 40 | 0.343 | 0.039 | | |
| | 50 | 0.327 | 0.056 | | |
| | 60 | 0.257 | 0.137 | | |
| | 70 | 0.191 | 0.121 | | |
| Zn | 0 | 0.157 | 0.030 | 2.121 | 0.133 |
| | 20 | 0.237 | 0.068 | | |
| | 40 | 0.198 | 0.046 | | |
| | 50 | 0.261 | 0.029 | | |
| | 60 | 0.213 | 0.039 | | |
| | 70 | 0.209 | 0.025 | | |
| Ni | 0 | 0.467 | 0.014 | 1.605 | 0.232 |
| | 20 | 0.515 | 0.123 | | |
| | 40 | 0.603 | 0.063 | | |
| | 50 | 0.641 | 0.137 | | |
| | 60 | 0.590 | 0.117 | | |
| | 70 | 0.660 | 0.100 | | |

#### 4.3.4.1 Chromium

The leaching of chromium from the sample was detected at the range of 0.191 – 0.343 mg/l. There was no statistical difference of chromium leached out of different proportions of bituminous fly ash (P-value = 0.310). So, the proportion of bituminous fly ash did not have an effect on the amount of leached chromium.

#### 4.3.4.2 Zinc

The range of zinc leached from the sample was between 0.157 and 0.261 mg/l. The mean of zinc leached out of different bituminous fly ash proportions showed no statistical difference (P-value = 0.133). So, the bituminous fly ash proportion did not have statistical relationship with the amount of zinc.

#### 4.3.4.3 Nickel

The amount of nickel leached from hollow concrete block was detected at the range of 0.467 – 0.660 mg/l. The analysis of the mean of nickel leached from different bituminous fly ash proportions showed that there was no statistical difference (P-value = 0.232). So, the bituminous fly ash proportion was not statistically related to the amount of leached nickel.

#### 4.3.4.4 Arsenic

As shown in Table 4.15 and Figure 4.9, the concentrations of arsenic leached from hollow concrete block were less than 0.001 mg/l, at all proportions of bituminous fly ash.

The results of correlation analyses (Table B-8 in appendix B) demonstrated that the correlation between bituminous fly ash proportion and leaching of chromium was not significant, r = -0.333 (P-value = 0.177). The results showed that it was slightly inversely correlated between the bituminous fly ash proportion and the leaching of chromium. That means, when bituminous fly ash proportion is increased, the leaching of chromium will be decreased.

Similarly, the correlation between bituminous fly ash proportion and leaching of zinc was not significant, r = 0.321 (P-value = 0.194). It was slightly positively correlated between the bituminous fly ash proportion and the leaching of zinc. That means, when bituminous fly ash proportion is increased, the leaching of zinc will be increased.

However, the correlation between bituminous fly ash proportion and leaching of nickel was significant, r = 0.589 (P-value = 0.01). The results showed that it was moderately correlated between the bituminous fly ash proportion and the leaching of nickel. That means, when bituminous fly ash proportion is increased, the leaching of nickel will be increased.

From the result, the leaching of nickel was significantly increased when bituminous fly ash proportion increased, which corresponded to the sixth hypothesis. In contrast, the decrease of leached chromium and the increase of leached zinc were not significant when bituminous fly ash proportions increased; these did not agree with the sixth hypothesis. Initially, the concentration of chromium and zinc in bituminous fly ash was very low; when it replaced cement in the hollow concrete block, the leaching of these heavy metals would also be very low.

The leaching of heavy metals tested in this study at all proportions were less than the standard of Soluble Threshold Limit Concentration specified in the Annoucement of Industry Ministry (B.E. 2548). So, the hollow concrete block product from replacement of Portland cement by bituminous fly ash will not potentially pose adverse effect to the environment.

## 4.4 Optimum proportion of bituminous fly ash

The optimum proportion of bituminous fly ash for hollow concrete block products were selected based on all of the experimental results and very careful analysis of this study. The main parameters are compressive strength and water absorption, under the criteria of Non-load-bearing concrete masonry units, stated by Thai Industrial Standard (TIS), Ministry of Industry, TIS 58-2533.

Results showed that compressive strength and water absorption in maximum portion of replacement Portland cement by bituminous fly ash appeared at 70% replacement. Both properties were within the requirement of TIS 58-2533. Moreover, when compared with properties of conventional hollow concrete block, the hollow concrete block produced in this study had a slightly lower quality. Comparison of properties from hollow concrete block (70% bituminous fly ash), conventional hollow concrete block, and standard of TIS 58-2533 is shown in Table 4.17. The conventional hollow concrete block was produced from general factory in proportion of cement per limestone crushing rock at 1 : 20 by weight.

**Table 4.17** Comparison of properties from hollow concrete block (70% bituminous fly ash), conventional hollow concrete block and standard of TIS 58-2533

| **Group of specimens** | **The properties** | |
|---|---|---|
| | Compressive strength ($kgf/cm^2$) | Water absorption (%) |
| Hollow concrete block (Bituminous fly ash 70%) | 45.0 | 14.5 |
| Conventional hollow concrete block | 63.0 | 11.7 |
| Std. TIS 58-2533 | Not less than 25 | Not more than 25 |

Moreover, the leaching of all tested heavy metals from hollow concrete block in maximum portion of replacement Portland cement by 70% bituminous fly ash was within the acceptable level of the Soluble Threshold Limit Concentration from the standard in the Annoucement of Industry Ministry (B.E. 2548). Therefore, hollow concrete block in maximum proportion of replacement Portland cement by 70% bituminous fly ash was the most optimum proportion for hollow concrete block product and would not potentially pose adverse effect to the environment.

## 4.5 Unit cost of hollow concrete block product

In this study, unit cost analysis of hollow concrete block product was calculated. It consists of cost and benefit from utilization of bituminous fly ash as mixture. The value of bituminous fly ash was neglected.

A small construction materials factory in Thamaka, Kanchanaburi province was selected as a case study for the unit cost analysis. The unit cost of hollow concrete block product was analyzed considering various costs such as raw material cost, labor cost, wear cost, and electrical cost, with quoted price referred to the construction materials factory in Thamaka, Kanchanaburi province. The prices of raw materials for producing the hollow concrete block of this factory are shown in Table 4.18.

**Table 4.18** Price of raw material for producing the hollow concrete block

| Detail | Units | Weight of Raw material | Cost/Unit (Baht) |
|---|---|---|---|
| - Cement (Elephant brand) | 1 Bag | 50 Kg | 135 Baht |
| - Cement (Tiger brand) | 1 Bag | 50 Kg | 125 Baht |
| - limestone crushing rock | 1 $m^3$ | 1600 Kg | 150 Baht |

**Source:** A small construction materials factory in Kanchanaburi province

The ratio of Portland cement to limestone crushing rock of this small factory was 1 : 20 by weight. They used Tiger brand of Portland cement. The production per cycle of the hollow concrete block of the small factory is 50 pieces. The proportion of raw material in one cycle of line product was shown in Table 4.19.

The ratio of raw material in this study was 1 : 5 by weight of cement and limestone crushing rock, respectively. Figure 4.7 showed the compressive strength of hollow concrete block product in all proportions. It was indicated that replacing cement by bituminous fly ash at 70% as the highest proportion. It was within the range required by the TIS 58-2533. Thus, in this study, the proportion from replacement cement by bituminous fly ash at 70% by weight was chosen. Elephant brand of Portland cement was used. The production per cycle of the hollow concrete block of replacement cement by bituminous fly ash at 70% is 60 pieces. Therefore, an adjustment was made so that the proportion of raw materials was for producing 50 pieces, equal to the production from the small factory. The proportion of raw material in one cycle of line product was shown in Table 4.19.

**Table 4.19** Proportion of raw material in one cycle of line product from small factory and this study

| **Raw material** | **In small factory** | | **In this study** | |
|---|---|---|---|---|
| | **Ratio** | **Proportion (Kg)** | **Ratio** | **Proportion (Kg)** |
| Bituminous fly ash | 0 | 0 | 0.7 | 39 |
| Portland cement | 1 | 19 | 0.3 | 17 |
| Limestone crushing rock | 20 | 381 | 5 | 277 |
| **Amount of product** | **50 piece** | | **50 piece** | |

Bituminous fly ash is lighter than cement; when replacing cement of equal weight, it results in a greater volume of mixture. That explains why 60 pieces of hollow concrete block could be obtained in this study, compared with 50 pieces produced from the small factory.

Calculation was made for cost per one piece using data of raw material price and amount of raw materials in Table 4.18 and 4.19, respectively. The value of bituminous fly ash was neglected. Calculation for cost per one piece was shown as follows.

**Calculation for raw material cost of hollow concrete block produced from the factory.**

Cost per piece of Portland cement (Tiger brand)

Hollow concrete blocks 50 piece used Portland cement 19 kg

So, Hollow concrete block 1 piece used Portland cement $\frac{19}{50}$ = 0.38 kg

Portland cement 50 kg = 125 baht

So, Portland cement 0.38 kg = $\frac{0.38 \times 125}{50}$ = 0.95 baht/piece

Cost per piece of limestone crushing rock

Hollow concrete blocks 50 piece used limestone crushing rock 381 kg

So, Hollow concrete block 1 piece used limestone crushing rock $\frac{381}{50}$ = 7.62 kg

limestone crushing rock 1600 kg = 150 baht

So, limestone crushing rock 7.62 kg = $\frac{7.62 \times 150}{1600}$ = 0.71 baht/piece

**Calculation for raw material cost of hollow concrete block produced from this study.**

Cost per piece of Portland cement (Elephant brand)

Hollow concrete blocks 50 piece used Portland cement 17 kg

So, Hollow concrete block 1 piece used Portland cement $\frac{17}{50}$ = 0.34 kg

Portland cement 50 kg = 135 baht

So, Portland cement 0.34 kg = $\frac{0.34 \times 135}{50}$ = 0.91 baht/piece

Cost per piece of limestone crushing rock

Hollow concrete blocks 50 piece used limestone crushing rock 277 kg

So, Hollow concrete block 1 piece used limestone crushing rock $\frac{277}{50}$ = 5.54 kg

limestone crushing rock 1600 kg = 150 bath

So, limestone crushing rock 5.54 kg = $\frac{5.54 \times 150}{1600}$ = 0.52 baht/piece

The cost of making hollow concrete block product was shown in Table 4.20 and 4.21.

**Table 4.20** Cost of making hollow concrete block product from the small factory (without bituminous fly ash)

| **Detail** | **Amount of product** | **Cost /mill (Baht)** | **Cost/piece (Baht)** |
|---|---|---|---|
| 1. Raw material | | | |
| - Portland cement | 50 | 47.5 | 0.95 |
| - limestone crushing rock | 50 | 35.5 | 0.71 |
| 2. Labor Cost | | | 0.50 |
| 3. Wear Cost | | | 0.12 |
| 4. Electric Cost | | | 0.03 |
| **Total** | | | **2.31** |

**Remark:** Labor cost, Wear cost and Electric cost was referred from construction materials factory in Thamaka, Kanchanaburi province.

**Table 4.21** Cost of making hollow concrete block product from replacement cement by bituminous fly ash at 70% by weight

| Detail | Amount of product | Cost /mill (Baht) | Cost/piece (Baht) |
|---|---|---|---|
| 1. Raw material | | | |
| - Portland cement | 50 | 45.5 | 0.91 |
| - limestone crushing rock | 50 | 26 | 0.52 |
| 2. Labor Cost | | | 0.50 |
| 3. Wear Cost | | | 0.12 |
| 4. Electric Cost | | | 0.03 |
| **Total** | | | **2.08** |

**Remark:** Labor cost, Wear cost and Electric cost was referred from construction materials factory in Thamaka, Kanchanaburi province.

Comparison of the cost per piece of hollow concrete block product from both formula were shown in Table 4.22.

**Table 4.22** Comparison of the cost per piece of hollow concrete block product from both formula

| Detail | Cost of hollow concrete block product (Baht/piece) | |
|---|---|---|
| | **In small factory** (Non bituminous fly ash) | **In this study** (Bituminous fly ash 70% in cement) |
| Portland cement | 0.95 | 0.91 |
| Limestone crushing rock | 0.71 | 0.52 |
| Labor Cost<br>Wear Cost<br>Electric Cost | 0.65 | 0.65 |
| **Total cost** | **2.31** | **2.08** |

One piece of hollow concrete block produced from replacement cement by bituminous fly ash at 70% in ratio 1 : 5 of cement to limestone crushing rock is 2.08 baht (Table 4.22). When compared with hollow concrete block produced from non bituminous fly ash in ratio 1 : 20 of cement to limestone crushing rock from a small factory; The cost for 1 piece is 2.31 baht. The profit should be the difference between 2.31 baht and 2.08 baht. The result is 0.23 baht for 1 piece (2.31 – 2.08 = 0.23 baht). Thus, in one time of production, 1000 pieces of products were generated; the cost of hollow concrete block product for each time would decrease as 230 baht.

# CHAPTER V
# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

### 5.1.1 The physical and chemical properties of bituminous fly ash

**5.1.1.1** The properties of bituminous fly ash were not identified as pozzolan in accordance with the ASTM C618-08. The fineness of bituminous fly ash retained on sieve No. 325 exceeded the standard which required that particle retained on sieve No. 325 must not be over 34 percent. The total amounts of $SiO_2$, $Al_2O_3$, and $Fe_2O_3$ in bituminous fly ash were 43.49 %. These values were less than those specified by ASTM 618-08. So, bituminous fly ash was not binder. The bituminous fly ash acted like replacement materials for limestone crushing rock more than Portland cement.

**5.1.1.2** The particle size and surface image of bituminous fly ash were detected by Scanning Electron Microscope (SEM). Bituminous fly ash particle size was in the range of 20 – 70 micrometers. Its texture showed many types such as spherical shape, edge shape and spongy shape, which was most prevalent.

**5.1.1.3** The concentrations of heavy metal including Cr, As, Ni and Zn in bituminous fly ash were less than the standard (Total Threshold Limit Concentration). These results showed that the bituminous fly ash from the textile factory in Samut Prakarn province would not potentially pose adverse effect to the environment.

### 5.1.2 The particle size distributions of limestone crushing rock

The particle size distributions of limestone crushing rock were within the range requirement of standard for concrete aggregates (Thai Industrial Standard No.

TIS 566 – 2528). So, the limestone crushing rock that used in this study was suitable to apply in hollow concrete block production.

### 5.1.3 The characteristics of hollow concrete block product

**5.1.3.1** The compressive strength of hollow concrete block was significantly decreased (P-value<0.05) when the replacement of Portland cement by bituminous fly ash increased. The non-binding property of bituminous fly ash and its spongy shape have some effects on the loss of compressive strength.

The compressive strength of hollow concrete block was significantly increased (P-value<0.05) when curing time increased, since hydration and pozzolanic reaction was longer. However, its compressive strength of maximum portion of 70% bituminous fly ash in all curing time was within the requirement standard of the Thai Industrial Standard No. TIS 58-2533.

**5.1.3.2** The water absorption of hollow concrete block was significantly increased (P-value<0.05) when replacement Portland cement by bituminous fly ash increased. Since, bituminous fly ash particles were spongy and porosity of surface, there were some effects on water absorption. This value increased when replacement of Portland cement by bituminous fly ash increased. However, its water absorption of maximum portion of 70% bituminous fly ash was within the requirement standard of the Thai Industrial Standard No. TIS 58-2533.

**5.1.3.3** The thermal conductivity of hollow concrete block was significantly decreased (P-value<0.05) when replacement of Portland cement by bituminous fly ash increased. If it needs to be used for protecting heat, further study should be developed.

**5.1.3.4** The leaching of nickel from hollow concrete block was significantly increased (P-value<0.05) when replacement Portland cement by bituminous fly ash increased. However, the leaching of chromium, zinc, nickel and arsenic from hollow concrete block at all proportions were less than the standard in the Annoucement of Industry Ministry (B.E. 2548). So, the hollow concrete block produced from replacement Portland cement by bituminous fly ash does not have harmful effects on the environment.

### 5.1.4 Optimum proportion of bituminous fly ash

The optimum proportion of bituminous fly ash for hollow concrete block products were selected based on the criteria of Non-load-bearing concrete masonry units, stated in the TIS 58-2533. The optimum proportions were selected maximum proportion of replacement Portland cement by 70% bituminous fly ash. The hollow concrete block products from 70% bituminous fly ash have water absorption of 14.5% and compressive strength of 45 $kg/cm^2$.

### 5.1.5 Utilization of hollow concrete block

The hollow concrete block product in this study was non-loading concrete based on the criteria of Non-load-bearing concrete masonry units, stated in the TIS 58-2533. Then, it would be suitable for non-loading concrete work such as construct the walls which non-loading other structure weight except weight of oneself.

### 5.1.6 Units cost

The hollow concrete block product from maximum proportion of replacement Portland cement by 70% bituminous fly ash reduced the cost per piece by 0.23 baht (not considering transportation cost). In one time of production, 1,000 pieces of products was generated. Therefore, 230 baht could be saved for each production of 1,000 pieces of hollow concrete blocks.

## 5.2 Recommendations

**5.2.1** Other types of cement for produce hollow concrete block should be studied.

**5.2.2** Further study should consider other properties of concrete from replacement of Portland cement by bituminous fly ash such as lightweight concrete or concrete for preventing the heat.

**5.2.3** Utilization of bituminous fly ash for other types of concrete such as concrete building brick, concrete flooring tiles, interlocking block should be considered.

**5.2.4** Comparison of properties of fly ash from other sources should be investigated.

**5.2.5** Bituminous bottom ash should also be studied for applying in concrete work.

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# APPENDICES

# APPENDIX A
# EXPERIMENT RESULTS

**Table A-1** The particle size distributions of limestone crushing rock

| Sieve size | Weight of Retain on sieve (g) | Percent of Retain on sieve (g) | Percent accumulate |
|---|---|---|---|
| (3/8-in.) | 0 | 0 | 0 |
| (No.4) | 0 | 0 | 0 |
| (No.8) | 227 | 22.7 | 22.7 |
| (No.16) | 180 | 18 | 40.7 |
| (No. 30) | 253 | 25.3 | 66 |
| (No. 50) | 130 | 13 | 79 |
| (No. 100) | 107 | 10.7 | 89.7 |
| Pan | 103 | 10.3 | 100 |
| Sum. | 1000 | 100 | |

**Table A-2** The pre-tests of W/B on forming and compressive strength of hollow concrete block.

| Bituminous fly ash % | W/B | Forming | Mean Weight (Kg) | Mean Compressive strength (Kg/m$^2$) |
|---|---|---|---|---|
| 0% | 0.5 | Yes | 7.2 | 155.2 |
| | 0.55 | Yes | 7.3 | 142.8 |
| | 0.6 | No | - | - |
| | 0.65 | No | - | - |
| | 0.7 | No | - | - |
| 20% | 0.5 | Yes | 6.5 | 60.5 |
| | 0.55 | Yes | 7.0 | 128.6 |
| | 0.6 | Yes | 7.0 | 130.1 |
| | 0.65 | No | - | - |
| | 0.7 | No | - | - |
| 40% | 0.5 | Yes | 6.3 | 51.5 |
| | 0.55 | Yes | 7.1 | 90.0 |
| | 0.6 | Yes | 7.1 | 104.0 |
| | 0.65 | Yes | 7.1 | 109.6 |
| | 0.7 | No | - | - |
| 50% | 0.5 | No | - | - |
| | 0.55 | Yes | 7.0 | 79.3 |
| | 0.6 | Yes | 7.0 | 89.0 |
| | 0.65 | Yes | 7.0 | 97.5 |
| | 0.7 | No | - | - |
| 60% | 0.5 | No | - | - |
| | 0.55 | Yes | 6.6 | 66.1 |
| | 0.6 | Yes | 6.9 | 70.4 |
| | 0.65 | Yes | 7.0 | 77.3 |
| | 0.7 | Yes | 7.0 | 80.0 |
| 70% | 0.5 | No | - | - |
| | 0.55 | No | - | - |
| | 0.6 | Yes | 6.0 | 32.9 |
| | 0.65 | Yes | 6.4 | 38.7 |
| | 0.7 | Yes | 6.5 | 44.2 |

**Remark** W/B : Water to Binder (Cement + BFA) ratio

**Table A-3** The compressive strength of hollow concrete block at bituminous fly ash was 0% in curing time 3, 7 and 14 days.

| Bituminous fly ash % | W/B | Curing time (days) | Number | Weight (Kg) | Compressive strength (Kg/m$^2$) | Mean (Kg/m$^2$) |
|---|---|---|---|---|---|---|
| 0% | 0.5 | 3 | 1 | 7.15 | 133.8 | 133.2 |
| | | | 2 | 7.25 | 135.5 | |
| | | | 3 | 7.18 | 128.3 | |
| | | | 4 | 7.20 | 132.2 | |
| | | | 5 | 7.22 | 136.0 | |
| | | 7 | 1 | 7.24 | 153.5 | 150.0 |
| | | | 2 | 7.15 | 150.1 | |
| | | | 3 | 7.20 | 147.0 | |
| | | | 4 | 7.25 | 150.0 | |
| | | | 5 | 7.21 | 149.6 | |
| | | 14 | 1 | 7.23 | 150.4 | 152.5 |
| | | | 2 | 7.25 | 152.9 | |
| | | | 3 | 7.31 | 153.2 | |
| | | | 4 | 7.20 | 150.1 | |
| | | | 5 | 7.25 | 155.7 | |

**Table A-4** The compressive strength of hollow concrete block at bituminous fly ash was 20% in curing time 3, 7 and 14 days.

| Bituminous fly ash % | W/B | Curing time (days) | Number | Weight (Kg) | Compressive strength (Kg/m$^2$) | Mean (Kg/m$^2$) |
|---|---|---|---|---|---|---|
| 20% | 0.6 | 3 | 1 | 7.08 | 116.6 | 116.6 |
| | | | 2 | 7.15 | 120.7 | |
| | | | 3 | 7.02 | 114.4 | |
| | | | 4 | 7.15 | 115.0 | |
| | | | 5 | 7.18 | 116.2 | |
| | | 7 | 1 | 7.20 | 130.1 | 127.9 |
| | | | 2 | 7.10 | 123.4 | |
| | | | 3 | 7.18 | 128.3 | |
| | | | 4 | 7.07 | 129.6 | |
| | | | 5 | 7.15 | 128.0 | |
| | | 14 | 1 | 7.23 | 133.5 | 132.6 |
| | | | 2 | 7.16 | 128.1 | |
| | | | 3 | 7.15 | 132.0 | |
| | | | 4 | 7.15 | 133.7 | |
| | | | 5 | 7.20 | 135.5 | |

**Table A-5** The compressive strength of hollow concrete block at bituminous fly ash was 40% in curing time 3, 7 and 14 days.

| Bituminous fly ash % | W/B | Curing time (days) | Number | Weight (Kg) | Compressive strength (Kg/m$^2$) | Mean (Kg/m$^2$) |
|---|---|---|---|---|---|---|
| 40% | 0.65 | 3 | 1 | 6.88 | 88.4 | 91.1 |
| | | | 2 | 7.10 | 91.1 | |
| | | | 3 | 7.08 | 92.6 | |
| | | | 4 | 7.15 | 96.2 | |
| | | | 5 | 7.05 | 87.1 | |
| | | 7 | 1 | 7.15 | 106.3 | 107.2 |
| | | | 2 | 7.03 | 105.3 | |
| | | | 3 | 7.00 | 102.0 | |
| | | | 4 | 7.15 | 109.6 | |
| | | | 5 | 7.18 | 112.9 | |
| | | 14 | 1 | 7.15 | 114.1 | 114.4 |
| | | | 2 | 7.10 | 113.8 | |
| | | | 3 | 7.20 | 117.1 | |
| | | | 4 | 7.07 | 109.4 | |
| | | | 5 | 7.18 | 117.7 | |

**Table A-6** The compressive strength of hollow concrete block at bituminous fly ash was 50% in curing time 3, 7 and 14 days.

| Bituminous fly ash % | W/B | Curing time (days) | Number | Weight (Kg) | Compressive strength (Kg/m$^2$) | Mean (Kg/m$^2$) |
|---|---|---|---|---|---|---|
| 50% | 0.65 | 3 | 1 | 6.95 | 86.8 | 85.0 |
| | | | 2 | 6.85 | 85.1 | |
| | | | 3 | 7.00 | 85.4 | |
| | | | 4 | 7.04 | 90.8 | |
| | | | 5 | 6.80 | 77.0 | |
| | | 7 | 1 | 7.08 | 97.5 | 94.9 |
| | | | 2 | 6.98 | 92.2 | |
| | | | 3 | 7.00 | 94.3 | |
| | | | 4 | 7.03 | 95.1 | |
| | | | 5 | 7.05 | 95.5 | |
| | | 14 | 1 | 6.95 | 97.2 | 100.8 |
| | | | 2 | 7.04 | 101.4 | |
| | | | 3 | 7.12 | 105.0 | |
| | | | 4 | 7.10 | 101.7 | |
| | | | 5 | 7.05 | 98.6 | |

**Table A-7** The compressive strength of hollow concrete block at bituminous fly ash was 60% in curing time 3, 7 and 14 days.

| Bituminous fly ash % | W/B | Curing time (days) | Number | Weight (Kg) | Compressive strength (Kg/m$^2$) | Mean (Kg/m$^2$) |
|---|---|---|---|---|---|---|
| 60% | 0.7 | 3 | 1 | 6.72 | 65.3 | 66.5 |
| | | | 2 | 6.80 | 68.7 | |
| | | | 3 | 6.74 | 61.8 | |
| | | | 4 | 6.82 | 66.4 | |
| | | | 5 | 6.95 | 70.4 | |
| | | 7 | 1 | 6.95 | 81.0 | 79.7 |
| | | | 2 | 6.85 | 78.6 | |
| | | | 3 | 7.02 | 80.3 | |
| | | | 4 | 6.80 | 75.5 | |
| | | | 5 | 6.90 | 83.0 | |
| | | 14 | 1 | 7.05 | 86.7 | 83.2 |
| | | | 2 | 6.90 | 82.9 | |
| | | | 3 | 6.85 | 86.1 | |
| | | | 4 | 6.80 | 76.0 | |
| | | | 5 | 7.10 | 84.5 | |

**Table A-8** The compressive strength of hollow concrete block at bituminous fly ash was 70% in curing time 3, 7 and 14 days.

| Bituminous fly ash % | W/B | Curing time (days) | Number | Weight (Kg) | Compressive strength (Kg/m$^2$) | Mean (Kg/m$^2$) |
|---|---|---|---|---|---|---|
| 70% | 0.7 | 3 | 1 | 6.51 | 30.2 | 32.1 |
| | | | 2 | 6.78 | 36.8 | |
| | | | 3 | 6.70 | 33.3 | |
| | | | 4 | 6.48 | 28.1 | |
| | | | 5 | 6.55 | 32.4 | |
| | | 7 | 1 | 6.65 | 44.2 | 45.0 |
| | | | 2 | 6.53 | 40.9 | |
| | | | 3 | 6.84 | 47.0 | |
| | | | 4 | 6.75 | 46.8 | |
| | | | 5 | 6.80 | 46.1 | |
| | | 14 | 1 | 6.80 | 51.7 | 50.3 |
| | | | 2 | 6.82 | 50.4 | |
| | | | 3 | 6.65 | 46.8 | |
| | | | 4 | 6.75 | 52.5 | |
| | | | 5 | 6.75 | 50.2 | |

**Table A-9** The water absorption of hollow concrete block at curing time 7 days

| Bituminous fly ash % | Number | Wet Weight (Kg) | Dry Weight (Kg) | Water absorption (%) | Mean |
|---|---|---|---|---|---|
| 0% | 1 | 7.71 | 7.21 | 6.9 | 6.8 |
| | 2 | 7.28 | 6.78 | 7.4 | |
| | 3 | 7.33 | 6.85 | 7.0 | |
| | 4 | 7.61 | 7.16 | 6.3 | |
| | 5 | 7.35 | 6.92 | 6.2 | |
| 20% | 1 | 7.28 | 6.84 | 6.4 | 7.3 |
| | 2 | 7.16 | 6.68 | 7.2 | |
| | 3 | 7.15 | 6.65 | 7.5 | |
| | 4 | 7.48 | 6.92 | 8.1 | |
| | 5 | 7.23 | 6.75 | 7.1 | |
| 40% | 1 | 7.13 | 6.6 | 8.0 | 9.7 |
| | 2 | 7.41 | 6.82 | 8.7 | |
| | 3 | 7.53 | 6.84 | 10.1 | |
| | 4 | 7.37 | 6.65 | 10.8 | |
| | 5 | 7.43 | 6.71 | 10.7 | |
| 50% | 1 | 7.1 | 6.42 | 10.6 | 10.7 |
| | 2 | 7.32 | 6.64 | 10.2 | |
| | 3 | 7.02 | 6.3 | 11.4 | |
| | 4 | 7.36 | 6.68 | 10.2 | |
| | 5 | 7.14 | 6.42 | 11.2 | |
| 60% | 1 | 7.32 | 6.55 | 11.8 | 12.3 |
| | 2 | 7.14 | 6.36 | 12.3 | |
| | 3 | 7.33 | 6.52 | 12.4 | |
| | 4 | 7.11 | 6.33 | 12.3 | |
| | 5 | 6.97 | 6.18 | 12.8 | |
| 70% | 1 | 7.1 | 6.27 | 13.2 | 14.5 |
| | 2 | 6.93 | 6.03 | 14.9 | |
| | 3 | 6.95 | 6.1 | 13.9 | |
| | 4 | 6.9 | 5.97 | 15.6 | |
| | 5 | 7.03 | 6.11 | 15.1 | |

**Table A-10** The thermal conductivity of hollow concrete block at curing time 7 days

| Bituminous fly ash % | Number | Thermal conductivity (W/m.k) | Mean |
|---|---|---|---|
| 0% | 1 | 1.5366 | 1.5372 |
| | 2 | 1.5353 | |
| | 3 | 1.5371 | |
| | 4 | 1.5413 | |
| | 5 | 1.5358 | |
| 20% | 1 | 1.5128 | 1.5183 |
| | 2 | 1.5214 | |
| | 3 | 1.5217 | |
| | 4 | 1.518 | |
| | 5 | 1.5175 | |
| 40% | 1 | 1.511 | 1.4883 |
| | 2 | 1.4855 | |
| | 3 | 1.4778 | |
| | 4 | 1.4869 | |
| | 5 | 1.4805 | |
| 50% | 1 | 1.4761 | 1.4919 |
| | 2 | 1.5135 | |
| | 3 | 1.479 | |
| | 4 | 1.4841 | |
| | 5 | 1.507 | |
| 60% | 1 | 1.5023 | 1.4872 |
| | 2 | 1.4874 | |
| | 3 | 1.483 | |
| | 4 | 1.4779 | |
| | 5 | 1.4852 | |
| 70% | 1 | 1.4712 | 1.4714 |
| | 2 | 1.4761 | |
| | 3 | 1.428 | |
| | 4 | 1.4974 | |
| | 5 | 1.4842 | |

**Table A-11** The leaching of heavy metal in hollow concrete block at curing time 7 days

| Bituminous fly ash % | Concentrations of heavy metal (mg/l) | | | |
|---|---|---|---|---|
| | Cr | Zn | Ni | As |
| 0% | 0.3010 | 0.1750 | 0.4810 | ND |
| | 0.3230 | 0.1730 | 0.4530 | ND |
| | 0.2610 | 0.1220 | 0.4670 | ND |
| Mean | 0.2950 | 0.1567 | 0.4670 | ND |
| 20% | 0.2510 | 0.2160 | 0.6330 | ND |
| | 0.3480 | 0.3110 | 0.3870 | ND |
| | 0.3710 | 0.1803 | 0.5240 | ND |
| Mean | 0.3233 | 0.2358 | 0.5147 | ND |
| 40% | 0.3725 | 0.2541 | 0.6540 | ND |
| | 0.3610 | 0.1810 | 0.5320 | ND |
| | 0.2980 | 0.1620 | 0.6220 | ND |
| Mean | 0.3438 | 0.1990 | 0.6027 | ND |
| 50% | 0.2640 | 0.2530 | 0.5990 | ND |
| | 0.3470 | 0.2370 | 0.5290 | ND |
| | 0.3700 | 0.2930 | 0.7940 | ND |
| Mean | 0.3270 | 0.2610 | 0.6407 | ND |
| 60% | 0.1130 | 0.1830 | 0.4610 | ND |
| | 0.2730 | 0.2570 | 0.6900 | ND |
| | 0.3850 | 0.2028 | 0.6180 | ND |
| Mean | 0.2570 | 0.2143 | 0.5897 | ND |
| 70% | 0.0520 | 0.2041 | 0.5470 | ND |
| | 0.2480 | 0.1890 | 0.7400 | ND |
| | 0.2740 | 0.2370 | 0.6920 | ND |
| Mean | 0.1913 | 0.2100 | 0.6597 | ND |

# APPENDIX B
# STATISTICAL ANALYSIS

**Table B-1** The statistical analysis of compressive strength at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 3 days

**Test of Homogeneity of Variance**

| | Levene Statistic | df 1 | df 2 | Sig. |
|---|---|---|---|---|
| Compressive strength | 0.262 | 5 | 24 | 0.929 |

**ANOVA Test**

**ANOVA**

Compressive strength

| | Sum of Squares | df | Mean Squares | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 32260.432 | 5 | 6452.086 | 512.314 | <0.001 |
| Within Groups | 302.256 | 24 | 12.594 | | |
| Total | 32562.688 | 29 | | | |

**Table B-1** The statistical analysis of compressive strength at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 3 days (cont.)

**Post Hoc Test**

Multiple Comparisons

Dependent Variable: Compressive strength

LSD

| (I) Bituminous Fly ash | (J) Bituminous Fly ash | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 0 | 20 | 16.5800(*) | 2.24446 | <0.001 | 11.9477 | 21.2123 |
| | 40 | 42.0800(*) | 2.24446 | <0.001 | 37.4477 | 46.7123 |
| | 50 | 48.1400(*) | 2.24446 | <0.001 | 43.5077 | 52.7723 |
| | 60 | 66.6400(*) | 2.24446 | <0.001 | 62.0077 | 71.2723 |
| | 70 | 101.0000(*) | 2.24446 | <0.001 | 96.3677 | 105.6323 |
| 20 | 0 | -16.5800(*) | 2.24446 | <0.001 | -21.2123 | -11.9477 |
| | 40 | 25.5000(*) | 2.24446 | <0.001 | 20.8677 | 30.1323 |
| | 50 | 31.5600(*) | 2.24446 | <0.001 | 26.9277 | 36.1923 |
| | 60 | 50.0600(*) | 2.24446 | <0.001 | 45.4277 | 54.6923 |
| | 70 | 84.4200(*) | 2.24446 | <0.001 | 79.7877 | 89.0523 |
| 40 | 0 | -42.0800(*) | 2.24446 | <0.001 | -46.7123 | -37.4477 |
| | 20 | -25.5000(*) | 2.24446 | <0.001 | -30.1323 | -20.8677 |
| | 50 | 6.0600(*) | 2.24446 | 0.013 | 1.4277 | 10.6923 |
| | 60 | 24.5600(*) | 2.24446 | <0.001 | 19.9277 | 29.1923 |
| | 70 | 58.9200(*) | 2.24446 | <0.001 | 54.2877 | 63.5523 |
| 50 | 0 | -48.1400(*) | 2.24446 | <0.001 | -52.7723 | -43.5077 |
| | 20 | -31.5600(*) | 2.24446 | <0.001 | -36.1923 | -26.9277 |
| | 40 | -6.0600(*) | 2.24446 | 0.013 | -10.6923 | -1.4277 |
| | 60 | 18.5000(*) | 2.24446 | <0.001 | 13.8677 | 23.1323 |
| | 70 | 52.8600(*) | 2.24446 | <0.001 | 48.2277 | 57.4923 |
| 60 | 0 | -66.6400(*) | 2.24446 | <0.001 | -71.2723 | -62.0077 |
| | 20 | -50.0600(*) | 2.24446 | <0.001 | -54.6923 | -45.4277 |
| | 40 | -24.5600(*) | 2.24446 | <0.001 | -29.1923 | -19.9277 |
| | 50 | -18.5000(*) | 2.24446 | <0.001 | -23.1323 | -13.8677 |
| | 70 | 34.3600(*) | 2.24446 | <0.001 | 29.7277 | 38.9923 |
| 70 | 0 | -101.0000(*) | 2.24446 | <0.001 | -105.6323 | -96.3677 |
| | 20 | -84.4200(*) | 2.24446 | <0.001 | -89.0523 | -79.7877 |
| | 40 | -58.9200(*) | 2.24446 | <0.001 | -63.5523 | -54.2877 |
| | 50 | -52.8600(*) | 2.24446 | <0.001 | -57.4923 | -48.2277 |
| | 60 | -34.3600(*) | 2.24446 | <0.001 | -38.9923 | -29.7277 |

*. The mean difference is significant at the 0.05 level.

**Table B-1** The statistical analysis of compressive strength at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 3 days (cont.)

Pearson Correlation

| | | Compressive strength | Bituminous fly ash proportion |
|---|---|---|---|
| Compressive strength | Pearson Correlation | 1.000 | -0.959** |
| | Sig.(2-tailed) | - | <0.001 |
| | N | 30 | 30 |
| Bituminous fly ash proportion | Pearson Correlation | -0.959** | 1.000 |
| | Sig.(2-tailed) | <0.001 | - |
| | N | 30 | 30 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

**Table B-2** The statistical analysis of compressive strength at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days

**Test of Homogeneity of Variance**

| | Levene Statistic | df 1 | df 2 | Sig. |
|---|---|---|---|---|
| Compressive strength | 0.884 | 5 | 24 | 0.507 |

**ANOVA Test**

**ANOVA**

Compressive strength

| | Sum of Squares | df | Mean Squares | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 33966.943 | 5 | 6793.389 | 850.219 | <0.001 |
| Within Groups | 191.764 | 24 | 7.990 | | |
| Total | 34158.707 | 29 | | | |

**Table B-2** The statistical analysis of compressive strength at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days (cont.)

**Post Hoc Test**

Multiple Comparisons

Dependent Variable: Compressive strength

LSD

| (I) Bituminous Fly ash | (J) Bituminous Fly ash | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 0 | 20 | 22.1600(*) | 1.78775 | <0.001 | 18.4703 | 25.8497 |
| | 40 | 42.8200(*) | 1.78775 | <0.001 | 39.1303 | 46.5097 |
| | 50 | 55.1200(*) | 1.78775 | <0.001 | 51.4303 | 58.8097 |
| | 60 | 70.3600(*) | 1.78775 | <0.001 | 66.6703 | 74.0497 |
| | 70 | 105.0400(*) | 1.78775 | <0.001 | 101.3503 | 108.7297 |
| 20 | 0 | -22.1600(*) | 1.78775 | <0.001 | -25.8497 | -18.4703 |
| | 40 | 20.6600(*) | 1.78775 | <0.001 | 16.9703 | 24.3497 |
| | 50 | 32.9600(*) | 1.78775 | <0.001 | 29.2703 | 36.6497 |
| | 60 | 48.2000(*) | 1.78775 | <0.001 | 44.5103 | 51.8897 |
| | 70 | 82.8800(*) | 1.78775 | <0.001 | 79.1903 | 86.5697 |
| 40 | 0 | -42.8200(*) | 1.78775 | <0.001 | -46.5097 | -39.1303 |
| | 20 | -20.6600(*) | 1.78775 | <0.001 | -24.3497 | -16.9703 |
| | 50 | 12.3000(*) | 1.78775 | <0.001 | 8.6103 | 15.9897 |
| | 60 | 27.5400(*) | 1.78775 | <0.001 | 23.8503 | 31.2297 |
| | 70 | 62.2200(*) | 1.78775 | <0.001 | 58.5303 | 65.9097 |
| 50 | 0 | -55.1200(*) | 1.78775 | <0.001 | -58.8097 | -51.4303 |
| | 20 | -32.9600(*) | 1.78775 | <0.001 | -36.6497 | -29.2703 |
| | 40 | -12.3000(*) | 1.78775 | <0.001 | -15.9897 | -8.6103 |
| | 60 | 15.2400(*) | 1.78775 | <0.001 | 11.5503 | 18.9297 |
| | 70 | 49.9200(*) | 1.78775 | <0.001 | 46.2303 | 53.6097 |
| 60 | 0 | -70.3600(*) | 1.78775 | <0.001 | -74.0497 | -66.6703 |
| | 20 | -48.2000(*) | 1.78775 | <0.001 | -51.8897 | -44.5103 |
| | 40 | -27.5400(*) | 1.78775 | <0.001 | -31.2297 | -23.8503 |
| | 50 | -15.2400(*) | 1.78775 | <0.001 | -18.9297 | -11.5503 |
| | 70 | 34.6800(*) | 1.78775 | <0.001 | 30.9903 | 38.3697 |
| 70 | 0 | -105.0400(*) | 1.78775 | <0.001 | -108.7297 | -101.3503 |
| | 20 | -82.8800(*) | 1.78775 | <0.001 | -86.5697 | -79.1903 |
| | 40 | -62.2200(*) | 1.78775 | <0.001 | -65.9097 | -58.5303 |
| | 50 | -49.9200(*) | 1.78775 | <0.001 | -53.6097 | -46.2303 |
| | 60 | -34.6800(*) | 1.78775 | <0.001 | -38.3697 | -30.9903 |

*. The mean difference is significant at the 0.05 level.

**Table B-2** The statistical analysis of compressive strength at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days (cont.)

Pearson Correlation

| | | Compressive strength | Bituminous fly ash proportion |
|---|---|---|---|
| Compressive strength | Pearson Correlation | 1.000 | -0.968** |
| | Sig.(2-tailed) | - | <0.001 |
| | N | 30 | 30 |
| Bituminous fly ash proportion | Pearson Correlation | -0.968** | 1.000 |
| | Sig.(2-tailed) | <0.001 | - |
| | N | 30 | 30 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

**Table B-3** The statistical analysis of compressive strength at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 14 days

**Test of Homogeneity of Variance**

| | Levene Statistic | df 1 | df 2 | Sig. |
|---|---|---|---|---|
| Compressive strength | 0.461 | 5 | 24 | 0.801 |

**ANOVA Test**

**ANOVA**

Compressive strength

| | Sum of Squares | df | Mean Squares | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 32897.843 | 5 | 6579.569 | 699.768 | <0.001 |
| Within Groups | 225.660 | 24 | 9.402 | | |
| Total | 33123.503 | 29 | | | |

**Table B-3** The statistical analysis of compressive strength at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 14 days (cont.)

**Post Hoc Test**

Multiple Comparisons

Dependent Variable: Compressive strength

LSD

| (I) Bituminous Fly ash | (J) Bituminous Fly ash | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 0 | 20 | 19.9000(*) | 1.93933 | <0.001 | 15.8974 | 23.9026 |
| | 40 | 38.0400(*) | 1.93933 | <0.001 | 34.0374 | 42.0426 |
| | 50 | 51.6800(*) | 1.93933 | <0.001 | 47.6774 | 55.6826 |
| | 60 | 69.2200(*) | 1.93933 | <0.001 | 65.2174 | 73.2226 |
| | 70 | 102.1400(*) | 1.93933 | <0.001 | 98.1374 | 106.1426 |
| 20 | 0 | -19.9000(*) | 1.93933 | <0.001 | -23.9026 | -15.8974 |
| | 40 | 18.1400(*) | 1.93933 | <0.001 | 14.1374 | 22.1426 |
| | 50 | 31.7800(*) | 1.93933 | <0.001 | 27.7774 | 35.7826 |
| | 60 | 49.3200(*) | 1.93933 | <0.001 | 45.3174 | 53.3226 |
| | 70 | 82.2400(*) | 1.93933 | <0.001 | 78.2374 | 86.2426 |
| 40 | 0 | -38.0400(*) | 1.93933 | <0.001 | -42.0426 | -34.0374 |
| | 20 | -18.1400(*) | 1.93933 | <0.001 | -22.1426 | -14.1374 |
| | 50 | 13.6400(*) | 1.93933 | <0.001 | 9.6374 | 17.6426 |
| | 60 | 31.1800(*) | 1.93933 | <0.001 | 27.1774 | 35.1826 |
| | 70 | 64.1000(*) | 1.93933 | <0.001 | 60.0974 | 68.1026 |
| 50 | 0 | -51.6800(*) | 1.93933 | <0.001 | -55.6826 | -47.6774 |
| | 20 | -31.7800(*) | 1.93933 | <0.001 | -35.7826 | -27.7774 |
| | 40 | -13.6400(*) | 1.93933 | <0.001 | -17.6426 | -9.6374 |
| | 60 | 17.5400(*) | 1.93933 | <0.001 | 13.5374 | 21.5426 |
| | 70 | 50.4600(*) | 1.93933 | <0.001 | 46.4574 | 54.4626 |
| 60 | 0 | -69.2200(*) | 1.93933 | <0.001 | -73.2226 | -65.2174 |
| | 20 | -49.3200(*) | 1.93933 | <0.001 | -53.3226 | -45.3174 |
| | 40 | -31.1800(*) | 1.93933 | <0.001 | -35.1826 | -27.1774 |
| | 50 | -17.5400(*) | 1.93933 | <0.001 | -21.5426 | -13.5374 |
| | 70 | 32.9200(*) | 1.93933 | <0.001 | 28.9174 | 36.9226 |
| 70 | 0 | -102.1400(*) | 1.93933 | <0.001 | -106.1426 | -98.1374 |
| | 20 | -82.2400(*) | 1.93933 | <0.001 | -86.2426 | -78.2374 |
| | 40 | -64.1000(*) | 1.93933 | <0.001 | -68.1026 | -60.0974 |
| | 50 | -50.4600(*) | 1.93933 | <0.001 | -54.4626 | -46.4574 |
| | 60 | -32.9200(*) | 1.93933 | <0.001 | -36.9226 | -28.9174 |

*. The mean difference is significant at the 0.05 level.

**Table B-3** The statistical analysis of compressive strength at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days (cont.)

Pearson Correlation

| | | Compressive strength | Bituminous fly ash proportion |
|---|---|---|---|
| Compressive strength | Pearson Correlation | 1.000 | -0.962** |
| | Sig.(2-tailed) | - | <0.001 |
| | N | 30 | 30 |
| Bituminous fly ash proportion | Pearson Correlation | -0.962** | 1.000 |
| | Sig.(2-tailed) | <0.001 | - |
| | N | 30 | 30 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

**Table B-4** The statistical analysis of compressive strength at the curing time 3, 7 and 14 days

**Test of Homogeneity of Variance**

| | Levene Statistic | df 1 | df 2 | Sig. |
|---|---|---|---|---|
| Compressive strength | .033 | 2 | 87 | .968 |

**ANOVA Test**

**ANOVA**

Compressive strength

| | Sum of Squares | df | Mean Squares | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 5337.866 | 2 | 2668.933 | 2.326 | 0.104 |
| Within Groups | 99844.898 | 87 | 1147.643 | | |
| Total | 105182.764 | 89 | | | |

**Table B-4** The statistical analysis of compressive strength at the curing time 3, 7 and 14 days (cont.)

Pearson Correlation

| | | Compressive strength | Curing time |
|---|---|---|---|
| Compressive strength | Pearson Correlation | 1 | 0.206(*) |
| | Sig.(2-tailed) | . | 0.026 |
| | N | 90 | 90 |
| Curing time | Pearson Correlation | 0.206(*) | 1 |
| | Sig.(2-tailed) | 0.026 | . |
| | N | 90 | 90 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

**Table B-5** Regression analysis of compressive strength of the bituminous fly ash proportion and curing time.

**Model Summary**

| Model | R | R square | Adjusted R square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | 0.938[a] | 0.881 | 0.879 | 11.94380 |
| 2 | 0.961[b] | 0.923 | 0.921 | 9.65166 |

a. Predictors: (Constant), bituminous fly ash

b. Predictors: (Constant), bituminous fly ash, curing time

**ANOVA(c)**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 92629.173 | 1 | 92629.173 | 649.326 | <0.001(a) |
| | Residual | 12553.591 | 88 | 142.654 | | |
| | Total | 105182.764 | 89 | | | |
| 2 | Regression | 97078.314 | 2 | 48539.157 | 521.060 | <0.001(b) |
| | Residual | 8104.450 | 87 | 93.155 | | |
| | Total | 105182.764 | 89 | | | |

a Predictors: (Constant), Bituminous fly ash

b Predictors: (Constant), Bituminous fly ash, Curing time

c Dependent Variable: Compressive strength

**Table B-5** Regression analysis of compressive strength of the bituminous fly ash proportion and curing time.

**Coefficients(a)**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 151.854 | 2.462 | | 61.684 | <0.001 |
| | Bituminous fly ash | -1.348 | 0.053 | - 0.938 | -25.482 | <0.001 |
| 2 | (Constant) | 139.481 | 2.676 | | 52.116 | <0.001 |
| | Bituminous fly ash | -1.348 | 0.043 | - 0.938 | -31.533 | <0.001 |
| | Curing time | 1.547 | 0.224 | 0.206 | 6.911 | <0.001 |

a Dependent Variable: Compressive strength

**Table B-6** The statistical analysis of water absorption at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days.

**Test of Homogeneity of Variance**

| | Levene Statistic | df 1 | df 2 | Sig. |
|---|---|---|---|---|
| Water absorption | 4.181 | 5 | 24 | 0.007 |

**ANOVA Test**

**ANOVA**

Water absorption

| | Sum of Squares | df | Mean Squares | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 221.843 | 5 | 44.369 | 74.340 | <0.001 |
| Within Groups | 14.324 | 24 | 0.597 | | |
| Total | 236.167 | 29 | | | |

**Table B-6** The statistical analysis of water absorption at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days (cont.)

**Post Hoc Test**

Multiple Comparisons

Dependent Variable: Water absorption

LSD

| (I) Bituminous Fly ash | (J) Bituminous Fly ash | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 0 | 20 | -.5000 | .48860 | 0.316 | -1.5084 | .5084 |
| | 40 | -2.9000(*) | .48860 | <0.001 | -3.9084 | -1.8916 |
| | 50 | -3.9600(*) | .48860 | <0.001 | -4.9684 | -2.9516 |
| | 60 | -5.5600(*) | .48860 | <0.001 | -6.5684 | -4.5516 |
| | 70 | -7.7800(*) | .48860 | <0.001 | -8.7884 | -6.7716 |
| 20 | 0 | .5000 | .48860 | 0.316 | -.5084 | 1.5084 |
| | 40 | -2.4000(*) | .48860 | <0.001 | -3.4084 | -1.3916 |
| | 50 | -3.4600(*) | .48860 | <0.001 | -4.4684 | -2.4516 |
| | 60 | -5.0600(*) | .48860 | <0.001 | -6.0684 | -4.0516 |
| | 70 | -7.2800(*) | .48860 | <0.001 | -8.2884 | -6.2716 |
| 40 | 0 | 2.9000(*) | .48860 | <0.001 | 1.8916 | 3.9084 |
| | 20 | 2.4000(*) | .48860 | <0.001 | 1.3916 | 3.4084 |
| | 50 | -1.0600(*) | .48860 | 0.040 | -2.0684 | -.0516 |
| | 60 | -2.6600(*) | .48860 | <0.001 | -3.6684 | -1.6516 |
| | 70 | -4.8800(*) | .48860 | <0.001 | -5.8884 | -3.8716 |
| 50 | 0 | 3.9600(*) | .48860 | <0.001 | 2.9516 | 4.9684 |
| | 20 | 3.4600(*) | .48860 | <0.001 | 2.4516 | 4.4684 |
| | 40 | 1.0600(*) | .48860 | <0.040 | .0516 | 2.0684 |
| | 60 | -1.6000(*) | .48860 | 0.003 | -2.6084 | -.5916 |
| | 70 | -3.8200(*) | .48860 | <0.001 | -4.8284 | -2.8116 |
| 60 | 0 | 5.5600(*) | .48860 | <0.001 | 4.5516 | 6.5684 |
| | 20 | 5.0600(*) | .48860 | <0.001 | 4.0516 | 6.0684 |
| | 40 | 2.6600(*) | .48860 | <0.001 | 1.6516 | 3.6684 |
| | 50 | 1.6000(*) | .48860 | 0.003 | .5916 | 2.6084 |
| | 70 | -2.2200(*) | .48860 | <0.001 | -3.2284 | -1.2116 |
| 70 | 0 | 7.7800(*) | .48860 | <0.001 | 6.7716 | 8.7884 |
| | 20 | 7.2800(*) | .48860 | <0.001 | 6.2716 | 8.2884 |
| | 40 | 4.8800(*) | .48860 | <0.001 | 3.8716 | 5.8884 |
| | 50 | 3.8200(*) | .48860 | <0.001 | 2.8116 | 4.8284 |
| | 60 | 2.2200(*) | .48860 | <0.001 | 1.2116 | 3.2284 |

*. The mean difference is significant at the 0.05 level.

**Table B-6** The statistical analysis of water absorption at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days (cont.)

Pearson Correlation

| | | Water absorption | Bituminous fly ash proportion |
|---|---|---|---|
| Water absorption | Pearson Correlation | 1.000 | 0.934** |
| | Sig.(2-tailed) | - | <0.001 |
| | N | 30 | 30 |
| Bituminous fly ash proportion | Pearson Correlation | 0.934** | 1.000 |
| | Sig.(2-tailed) | <0.001 | - |
| | N | 30 | 30 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

**Table B-7** The statistical analysis of thermal conductivity at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days

**Test of Homogeneity of Variance**

| | Levene Statistic | df 1 | df 2 | Sig. |
|---|---|---|---|---|
| Thermal conductivity | 2.755 | 5 | 24 | 0.042 |

**ANOVA Test**

**ANOVA**

Thermal conductivity

| | Sum of Squares | df | Mean Squares | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 0.014 | 5 | 0.003 | 13.848 | <0.001 |
| Within Groups | 0.005 | 24 | 0.000 | | |
| Total | 0.020 | 29 | | | |

**Table B-7** The statistical analysis of thermal conductivity at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days (cont.)

**Post Hoc Test**

Multiple Comparisons

Dependent Variable: Thermal conductivity

LSD

| (I) Bituminous Fly ash | (J) Bituminous Fly ash | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 0 | 20 | .018940(*) | .0091508 | 0.049 | .000054 | .037826 |
| | 40 | .048880(*) | .0091508 | <0.001 | .029994 | .067766 |
| | 50 | .045280(*) | .0091508 | <0.001 | .026394 | .064166 |
| | 60 | .050060(*) | .0091508 | <0.001 | .031174 | .068946 |
| | 70 | .065840(*) | .0091508 | <0.001 | .046954 | .084726 |
| 20 | 0 | -.018940(*) | .0091508 | 0.049 | -.037826 | -.000054 |
| | 40 | .029940(*) | .0091508 | 0.003 | .011054 | .048826 |
| | 50 | .026340(*) | .0091508 | 0.008 | .007454 | .045226 |
| | 60 | .031120(*) | .0091508 | 0.002 | .012234 | .050006 |
| | 70 | .046900(*) | .0091508 | <0.001 | .028014 | .065786 |
| 40 | 0 | -.048880(*) | .0091508 | <0.001 | -.067766 | -.029994 |
| | 20 | -.029940(*) | .0091508 | 0.003 | -.048826 | -.011054 |
| | 50 | -.003600 | .0091508 | 0.697 | -.022486 | .015286 |
| | 60 | .001180 | .0091508 | 0.898 | -.017706 | .020066 |
| | 70 | .016960 | .0091508 | 0.076 | -.001926 | .035846 |
| 50 | 0 | -.045280(*) | .0091508 | <0.001 | -.064166 | -.026394 |
| | 20 | -.026340(*) | .0091508 | 0.008 | -.045226 | -.007454 |
| | 40 | .003600 | .0091508 | 0.697 | -.015286 | .022486 |
| | 60 | .004780 | .0091508 | 0.606 | -.014106 | .023666 |
| | 70 | .020560(*) | .0091508 | 0.034 | .001674 | .039446 |
| 60 | 0 | -.050060(*) | .0091508 | <0.001 | -.068946 | -.031174 |
| | 20 | -.031120(*) | .0091508 | 0.002 | -.050006 | -.012234 |
| | 40 | -.001180 | .0091508 | 0.898 | -.020066 | .017706 |
| | 50 | -.004780 | .0091508 | 0.606 | -.023666 | .014106 |
| | 70 | .015780 | .0091508 | 0.097 | -.003106 | .034666 |
| 70 | 0 | -.065840(*) | .0091508 | <0.001 | -.084726 | -.046954 |
| | 20 | -.046900(*) | .0091508 | <0.001 | -.065786 | -.028014 |
| | 40 | -.016960 | .0091508 | 0.076 | -.035846 | .001926 |
| | 50 | -.020560(*) | .0091508 | 0.034 | -.039446 | -.001674 |
| | 60 | -.015780 | .0091508 | 0.097 | -.034666 | .003106 |

*. The mean difference is significant at the 0.05 level.

**Table B-7** The statistical analysis of thermal conductivity at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days (cont.)

Pearson Correlation

| | | Thermal conductivity | Bituminous fly ash proportion |
|---|---|---|---|
| Thermal conductivity | Pearson Correlation | 1.000 | -0.837** |
| | Sig.(2-tailed) | - | <0.001 |
| | N | 30 | 30 |
| Bituminous fly ash proportion | Pearson Correlation | -0.837** | 1.000 |
| | Sig.(2-tailed) | <0.001 | - |
| | N | 30 | 30 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

**Table B-8** The statistical analysis of leaching of heavy metal at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days

**Test of Homogeneity of Variance**

| Parameter | Levene Statistic | df 1 | df 2 | Sig. |
|---|---|---|---|---|
| Cr | 2.226 | 5 | 12 | 0.119 |
| Zn | 1.442 | 5 | 12 | 0.279 |
| Ni | 1.636 | 5 | 12 | 0.224 |

**ANOVA Test**

**ANOVA**

Leaching of heavy metal

| | | Sum of Squares | df | Mean Squares | F | Sig. |
|---|---|---|---|---|---|---|
| Cr | Between Groups | 0.048 | 5 | 0.010 | 1.348 | 0.310 |
| | Within Groups | 0.086 | 12 | 0.007 | | |
| | Total | 0.135 | 17 | | | |
| Zn | Between Groups | 0.019 | 5 | 0.004 | 2.121 | 0.133 |
| | Within Groups | 0.021 | 12 | 0.002 | | |
| | Total | 0.040 | 17 | | | |
| Ni | Between Groups | 0.083 | 5 | 0.017 | 1.605 | 0.232 |
| | Within Groups | 0.124 | 12 | 0.010 | | |
| | Total | 0.207 | 17 | | | |

**Table B-8** The statistical analysis of leaching of heavy metal at the bituminous fly ash proportion of 0%, 20%, 40%, 50%, 60% and 70% in curing time 7 days (cont.)

Pearson Correlation

| | | Bituminous fly ash proportion | Cr |
|---|---|---|---|
| Bituminous fly ash proportion | Pearson Correlation | 1 | - 0.333 |
| | Sig.(2-tailed) | . | 0.177 |
| | N | 18 | 18 |
| Cr | Pearson Correlation | - 0.333 | 1 |
| | Sig.(2-tailed) | 0.177 | . |
| | N | 18 | 18 |

Pearson Correlation

| | | Bituminous fly ash proportion | Zn |
|---|---|---|---|
| Bituminous fly ash proportion | Pearson Correlation | 1 | 0.321 |
| | Sig.(2-tailed) | . | 0.194 |
| | N | 18 | 18 |
| Zn | Pearson Correlation | 0.321 | 1 |
| | Sig.(2-tailed) | 0.194 | . |
| | N | 18 | 18 |

Pearson Correlation

| | | Bituminous fly ash proportion | Ni |
|---|---|---|---|
| Bituminous fly ash proportion | Pearson Correlation | 1 | 0.589 |
| | Sig.(2-tailed) | . | 0.010 |
| | N | 18 | 18 |
| Ni | Pearson Correlation | 0.589 | 1 |
| | Sig.(2-tailed) | 0.010 | . |
| | N | 18 | 18 |

# BIOGRAPHY

| | |
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