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ULTILIZATION OF FLY ASH FROM BIOMASS POWER PLANT IN LIGHTWEIGHT CONCRETE

Mr. Chatri Saosub

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By	Mr. Chatri Saosub
Field of Study	Environmental Management
Thesis Principal Advisor	Assistant Professor Manaskorn Rachakornkij, Ph.D.

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

Vice President
.... Acting Dean of the Graduate School
(Assistant Professor M.R. Kalaya Tingsabadh, Ph.D.)

THESIS COMMITTEE

.... Chairperson
(Chantra Tongcumpou, Ph.D.)

.... Thesis Principal Advisor
(Assistant Professor Manaskorn Rachakornkij, Ph.D.)

.... Member
(Assistant Professor Khemarath Osathaphan, Ph.D)

.... External Member
(Mr.Vinai Yimyam)

ชาตรี สาวทรัพย์ : การใช้ประโยชน์เถ้าลอยจากโรงไฟฟ้าชีวมวลในคอนกรีตมวลเบา (UTILIZATION OF FLY ASH FROM BIOMASS POWER PLANT IN LIGHTWEIGHT CONCRETE) อ. ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ.ดร.มนัสกร ราชากรกิจ , 96 หน้า

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาและพัฒนาคอนกรีตมวลเบาโดยนำของเสียจากโรงไฟฟ้าชีวมวล ได้แก่ เถ้าลอยแกลบ และเถ้าลอยชีวมวลผสม มาเป็นวัตถุดิบหลักเพื่อทดแทนการใช้ปูนซีเมนต์ปอร์ตแลนด์ โดยมีการทดลองเพื่อศึกษาวิธีที่เหมาะสมในการผลิตคอนกรีตมวลเบาแบบอบไอน้ำ และหาระยะเวลาที่เหมาะสมของการบ่มด้วยไอน้ำ โดยพิจารณาจากความหนาแน่น และกำลังรับแรงอัดของคอนกรีตมวลเบารวมถึงใช้ในการศึกษาหาปริมาณที่เหมาะสมของผงอลูมิเนียม และอัตราส่วนระหว่างน้ำและวัสดุเชื่อมประสาน เพื่อใช้ตลอดการทดลอง โดยที่จะทำการศึกษาผลของการแทนที่จากพารามิเตอร์ต่างๆ ได้แก่ ความหนาแน่น กำลังรับแรงอัด และการดูดกลืนน้ำ ตามลำดับ ผลการศึกษาพบว่า ระยะเวลาที่เหมาะสมของการบ่มด้วยไอน้ำสำหรับการทดลองนี้คือ 14 ชั่วโมง ส่วนปริมาณที่เหมาะสมของการเติมผงอลูมิเนียม อัตราส่วนระหว่างน้ำต่อวัสดุเชื่อมประสาน สัดส่วนที่เหมาะสมของวัสดุประสาน และวัสดุมวลรวม คือ 0.3% โดยน้ำหนักของแข็งทั้งหมด 0.472 และ 55: 45 ตามลำดับ และใช้ตลอดการทดลองของการแทนที่ปูนซีเมนต์ด้วยเถ้าลอยชีวมวล จากการศึกษาพบว่าที่ร้อยละที่สูงขึ้นของการแทนที่ปอร์ตแลนด์ซีเมนต์ด้วยเถ้าลอยชีวมวลมีผลต่อการลดลงของค่าความหนาแน่น อีกทั้งที่ร้อยละของการแทนที่ที่สูงขึ้นนำมาซึ่งการลดลงของค่าใช้จ่ายในการผลิตคอนกรีตมวลเบา และหากจะคำนึงถึงการแทนที่ในปริมาณที่สูงสุด อีกทั้งยังไม่ส่งผลกระทบกับคุณสมบัติของคอนกรีตมวลเบา เมื่อเทียบกับชิ้นควบคุม พบว่าร้อยละ 30 ของการแทนที่ที่โดยน้ำหนักของปูนซีเมนต์มีความเหมาะสมมากที่สุด ดังนั้น จึงสามารถสรุปได้ว่าเถ้าลอยชีวมวลจากโรงไฟฟ้าชีวมวล สามารถใช้แทนที่ปอร์ตแลนด์ซีเมนต์ซึ่งเป็นส่วนประกอบหลักในการผลิตคอนกรีตมวลเบา นอกจากจะเป็นการจัดการของเสียที่สร้างมูลค่าแล้ว ยังเป็นการลดปัญหาเรื่องมลพิษทางอากาศ และการฝังกลบอีกด้วย

สาขาวิชา การจัดการสิ่งแวดล้อม (สหสาขาวิชา) ลายมือชื่อนิสิต ชาตรี สาวทรัพย์
ปีการศึกษา 2550 ลายมือชื่ออาจารย์ที่ปรึกษาวิทยานิพนธ์หลัก

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The purpose of this research is to study and develop lightweight concrete using waste products; namely, rice husk ash and biomass fly ash. The wastes were obtained from a biomass power plant as replacement materials for main ingredient, Portland cement, to make lightweight concrete. Experimental programs involve determination of proper manufacturing method of autoclaved aerated lightweight concrete using blowing agent and duration of curing time based on density and compressive strength of lightweight concrete. Optimum amount of aluminium powder and water-to-binder ratio were investigated for all mixes throughout the experimental programs. Physical and chemical characteristics of biomass fly ash were also determined. The physical and mechanical properties of lightweight concrete samples evaluated include dry density, compressive strength, and water absorption. The testing results showed that the optimum duration of high pressure curing was 14 hours. While the optimal amount of aluminium content, water–to-binder ratio, and binder-to-aggregate ratio of lightweight concrete were 0.3% of aluminium powder by total solid weight, 0.472, and 55:45, respectively. The use of fly ash as the main ingredient to replace Portland cement resulted in decrease in density significantly. From main testing results, it can be used to noted that the optimal mix proportion be 30%RH, 30%B_3 which used the highest amount of biomass fly ash replacement and did not compromise the aerated lightweight mortar properties as compared with control mix.. Finally, it can be concluded that fly ash from a biomass power plant can be sufficiently used as cement replacement for lightweight concrete block production. Beside the utilization of the wastes, biomass fly ash, pollution, and disposal problems can also be mitigated as a result.

Field of Study..Environmental Management. Student's Signature..Chatri Saosub.....
Academic year…2007……………………… Principal Advisor's Signature.......

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LIST OF ABBREVIATIONS

AAC	Autoclaved Aerated Concrete
ASTM	America Society for Testing and Materials
Al	Aluminium
B_3	Biomass Feed Recipe #3
B_4	Biomass Feed Recipe #4
BFR#3	Biomass Feed Recipe #3
BFR#4	Biomass Feed Recipe #4
C_2S	Dicalcium silicate
C_3S	Tricalcium silicate
C_3A	Tricalcium aluminite
C_3AF	Tetracalcium aluminoferrite
Ca	Calcium
CH	Calcium hydroxide
C-S-H	Calcium silicate hydrate
Fe	Iron
g/cm^3	Gram per cubic centimeter
kg/m^3	Kilogram per cubic meter
kN	Kilo newton
ksc	Kilogram per square centimeter
L	Liter
LOI	Loss on Ignite
RH	Rice husk
Si	Silica
W/C	water-to-cement ratio
W/TS	water-to-total solid ratio
XRD	X-ray diffraction spectrometer
XRF	X-ray fluorescence spectrometer
Am	Amorphous

CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

Global problems stemming from energy crisis at present have caused economic downturns and bankruptcy for many businesses because of the rising cost of electricity. It is thus necessary to search for new sources of thermal energy or "alternative fuels" that can be used to sustain demands of the country. Currently, biomass power plant is one solution that could solve this problem. About 12 percent of world's energy consumption at present has come from biomass energy and tends to increase rapidly in the future (NEPO,2000)due to the fact that biomass fuels are renewable and greenhouse gas neutral (biomass combustion releases no more carbon dioxide than absorbed during the plant's growth). (Kuprianov et. al., 2006) Biomass fuels contain little sulfur compared to coal (reduced sulfur dioxide emissions) and have lower combustion temperatures (reduced nitrogen oxide emissions). In spite of the fact that use of biomass energy has many advantages in environmental aspects, economic aspects are always the primary factor to be considered before anything else. Biomass utilization will be favored over the ordinary thermal conversion processes when there is enough economic incentive. For Thailand which is agricultural and developing country, there is a strong potential for biomass to be used as fuel. However, utilization of biomass energy in thermal processes also produces fly ash and bottom ash as by-products that could resulting on air polluted and disposal problems

Due to the expansion of homebuilding industry in Thailand during the past few years, the demand for Autoclave Aerated Concrete (AAC) products has been on the rise because of their outstanding properties, for instance, lighter weight as a resulting of faster construction and better handling than conventional concrete. Thus, in this study, the by-product from combustion process of biomass power plant, fly ash, which are waste materials, were used to replace some of Portland cement in the mix as primary raw materials for reduce the cost of Autoclaved Aerated Lightweight

Concrete's initial cost and it is also mitigate air polluted and disposal problems that cause by them. As a result, it seems necessary to conduct research work and apply appropriate technology to produce the good quality lightweight concrete product for construction purpose and other needs.

1.2 Objectives

The purposes of this research are to study and develop autoclaved aerated lightweight concrete using fly ash from biomass power plant in Chacheangsao province, Thailand, as a replacement material for Portland cement. Main tasks of this research include the followings:

1.2.1 To characterize physical and chemical properties of fly ashes resulting from combustion of three biomass feed recipes.

1.2.2 To optimize lightweight mortar mix proportion and water content for the physical properties and performance of autoclaved aerated lightweight concrete

1.2.3 To determine the physical and mechanical properties of autoclaved aerated lightweight concrete using the biomass fly ash as the main ingredient from this study to compare with the properties of lightweight mortar of TIS 1505-1998.

1.3 Hypothesis

As proposed in this study, fly ash will be used as a partial replacement for cement in autoclaved aerated lightweight concrete, higher replacement ratios should have some effects on the physical and mechanical properties of autoclaved aerated lightweight concrete. On the other hand, we can find the optimal ratios that may not present significant compromises on these properties.

1.4 Scope of the Study

This study deals with materials, specimens, and test program as follows:

1.4.1 The dimension of specimen of the testing is 50x50x50 mm. (cube)

1.4.2 Fly ash was used as a partial replacement material for Ordinary Portland Cement (OPC) in trial mixes

1.4.3 Aluminium powder is used as a blowing agent

1.4.4 Water-to-Total solid ratio is 0.26-0.32 throughout the experimental programs

1.4.5 The curing technique uses high pressure steam, or autoclave

1.4.6 There are many recipes of bioenergy that were used for power generation in this firm, TPS Co. Ltd., in Chachoengsao province, Thailand, but these three different recipes of biomass fly ash were selected base on the seasonal availability and heating value. They were used as primary raw material in main testing program.

1.4.7 In this study, the parameters namely, desired water absorption, density, and compressive strength which are the required parameters for quality control of autoclaved aerated concrete manufacturer were methodically determined and compared for all mixes in order to identify the optimal percentage of replacement.

CHAPTER II

BACKGROUND AND LITERATURE REVIEW

In this part, the currently information of lightweight concrete, theory, concept, and literature review that play a crucial role to the study criteria and experimental program in this research were gathered as follow:

2.1 Biomass power plant
2.2 Lightweight concrete
2.3 Autoclaved aerated lightweight concrete
2.4 The Properties of aerated concrete
2.5 Autoclaved aerated concrete in Thailand
2.6 The using of fly ash as main ingredient in concrete

2.1 Biomass Power Plant

Currently, significant level of the world's energy comes from use of biomass fuels which include items as diverse as residential yard waste, manure, agricultural residues, and dedicated energy crops. In industrialized nations, bioenergy facilities typically use biomass fuels in large industrial cogeneration applications. Increasing industrialization and household income are driving the economies of developing nations to implement cleaner and more efficient biomass technologies. Environmental concerns may help make biomass an economically competitive fuel. Because biomass fuels are generally less dense, lower in energy content, and more difficult to handle than fossil fuels, they usually do not compare favorably to fossil fuels on an economic basis. However, biomass fuels have several important environmental advantages. Biomass fuels are renewable, and sustainable use is greenhouse gas neutral (biomass combustion releases no more carbon dioxide than absorbed during the plant's growth). Biomass fuels contain little sulfur compared to coal (reduced sulfur dioxide emissions) and have lower combustion temperatures (reduced nitrogen oxide emissions).

Anyhow, even the use of biomass energy has many advantages in environmental aspect, economic incentive is always the primary factor that human will realize before its environmental meaning. Biomass utilization will be favored over the ordinary thermal conversion processes when there is enough economic incentive. For Thailand which is agricultural and developing country, there is a strong potential for biomass to be used as fuel. There are three main sources of biomass stream as follows: *Agricultural crops*, such as sugar cane, cassava, corn, and etc; *Agricultural residues* such as, rice straw from rice paddies, cassava rhizome from tapioca fields, and corncobs from cornfields; and *Agro-industrial wastes* such as, residues from palm oil extraction, rice husk from rice mills, molasses, and bagasse from sugar refineries, municipal solid waste, etc. In 2004, generation of total biomass in Thailand was about 75 million tons, but half of that was unused (50 million tons) as shown in Table 2.1.

Table 2.1 Generation of Three Main Types of Biomass Residues in 2004

Product	Production	Agricultural residues	Residues	Available unused residue
Sugar cane	66,666	Bagasse	20,399	4,223
		Trash	21,171	20,873
Rice	29,422	Rice husk	6,173	3,044
		Rice straw	11,998	8,207
Oil palm	28,543	EFB*	1,226	716
		Fiber	721	97
		Shells	240	9
		Fronds	12,767	12,767
Total			74695	49,936

* EFB referred to empty fruit branch

Source: Papomg et al (2004).

Besides the utilization of biomasses in conventional thermal process such as cooking and others. Currently, in Thailand, biomass materials can be used to produce thermal energy directly, or liquid fuels such as ethanol for automobile that have lower environmental impact than traditional fossil fuels, ethanol can be used in special kind of cars that are made for using alcohol and can also be blended with gasoline to produce gasoline to produce gasohol to reduce the use of non-renewable resources. Another biomass utilization technology, which is widely practiced in Thailand at the moment, is biomass-fire power plants; there are five main kinds of biomass conversion system in Thailand as follows:

2.1.1 Mass Burn Stoker Boiler

Mass burn stoker boilers offer very good fuel flexibility, but these units are typically larger and more costly than the other types of boilers. This is because mass burn units have historically been designed to burn unprocessed municipal solid waste (MSW). MSW can vary significantly in size, heating value, and moisture content, so that requires special accommodations in the boiler design. Fuel flexibility and the ability to accommodate a wide variation in fuel properties are generally not required for biomass boilers.

2.1.2 Stoker Boiler

Stoker combustion is a proven technology that has been successfully used with biomass fuels (primarily wood) for many years. In the vibrating grate variety, fuel is fed through the front wall of the boiler above the grate. Because most biomass readily devolatilizes, much of the fuel burns in suspension above the grate. Unburned articles and ash settles on the grate and protect it from the high combustion temperatures. The vibration of the grate causes ash accumulated on the grate to move toward the discharge end of the grate where it falls into the bottom ash collection and conveying system. Because stoker boilers have been in widespread use for many years, local manufacturers and maintenance companies are available in many countries (Thailand is included). For this reason, capital costs for stoker boilers can be comparatively low.

2.1.3 Bubbling Fluidized Bed

Combustion of biomass fuels in fluidized beds has been commercially applied for long times probably more than 20 years. A bubbling fluidized bed consists of fuel, ash from the fuel, inert material (sand), and possibly a sorbent (e.g. limestone) to reduce sulfur emissions. The fluidized state of the bed is maintained by hot air flowing upward through the bed. The air causes the bed material to rise and separate, and creates circulation patterns throughout the bed. Because of the turbulent bed mixing, heat transfer rates are very high and combustion efficiency is good. Consequently, combustion temperatures can be kept low compared to stoker boilers. This reduces NOx formation and is an advantage with biomass fuels, because they may have relatively low ash fusion temperatures. Low ash fusion temperatures can lead to excessive boiler slagging. Due to the large amount of heat stored in the bed material, the bubbling fluidized bed has the potential to accommodate a wider range of fuel heating values and moisture contents than the stoker boiler. This may make them an ideal choice for centrally located power plants fed with several different biomass residues. However, despite the apparent acceptance of bubbling bed technology, recent bubbling bed experience in Thailand is rather discouraging.

2.1.4 Circulating Fluidized Bed

Circulating fluidized bed units also offer a high degree of fuel flexibility and would be a suitable technology for burning biomass. While early circulating fluidized bed units were in the size range appropriate for most biomass plants (10-50 MW), present circulating fluidized bed technology is focusing on fossil fueled units of 200 to 300 MW. Although manufacturers quote small circulating fluidized bed units, these units generally cost more than other combustion technologies, making them difficult to justify for biomass plants. Additionally, on a recent 35 MW rice husk power project, one of the major circulating fluidized bed suppliers declined to bid. The supplier stated that the technology was not the best approach to burning rice husk or rice straw.

2.1.5 Gasification

Another potential conversion option is gasification. Gasification is typically characterized as incomplete combustion of a fuel to produce a fuel gas of low to medium heating value. Gasification lies between the extremes of combustion and pyrolysis (anaerobic thermal decomposition) and occurs as the amount of oxygen supplied to the burning biomass is decreased. Combustible constituents in the fuel gas include methane, carbon monoxide, hydrogen, and some higher hydrocarbons; inert constituents are primarily nitrogen, carbon dioxide, and water vapor. Depending on the gasification scheme used, the heating value of the fuel gas generally ranges between 3.7 and 7.5 MJ/Nm^3 (100-200 Btu/scf) for direct gasifiers, and between 11 and 17 MJ/Nm^3 (300- 450 Btu/scf) for indirect gasifiers. By comparison, natural gas has a heating value of around 37 MJ/Nm^3 (1,000 Btu/scf). Direct gasifiers have been used extensively worldwide. Gasification expands the use of solid biomass to include all the uses of natural gas and petroleum-based fuels, giving it a distinct advantage over combustion. Besides providing higher efficiency power generation through advanced processes, the fuel gas can be used for the chemical synthesis of methanol, ammonia, and gasoline. Gasification is also better suited for providing precise process heat control (e.g., for glass-making). Energy conversion options for the fuel gas include close-coupled boilers, internal combustion engines, gas turbines, and fuel cells. Of these, only close-coupled boilers are considered technically mature for large scale applications.

Each type of the processes mentioned above has different advantages and disadvantages. Theses systems are commercially available and have been operated in Thailand. Stoker boiler is widely in use, but it is not always an appropriate choice, for Actually, fluidize bed system is the most suitable choice for biomass burning due to its ability to accommodate wide range of moisture content and particle size of biomass materials. Gasification is another interesting choice, but it lacks commercial acceptance.

Case study:

Thai Power Supply

There are four power plants operated by Thai Power Supply, Ltd. which is located in Chachoengsao province, eastern Thailand. This study focuses on biomass power plant no.3, and biomass power plant no.4. Power plant no. 3 has the capacity of about 10.4 MW and used rice husks, wood wastes, coal, corn cobs, sawdust as biomass fuels. The capacity to produce electricity about 37.15 MW for biomass power plant no.4 Biomass fuels are rice husk, wood waste, coal, and palm residues. Both of these two plants are used circulating fluidized bed technology for transformation of biomass fuel to heats. These processes are: fuels are prepared for use by crushing. After crushed, it is mixed with air and blown into the boiler to heat water to produce steam. The steam, flows into a turbine, which spins a generator to produce electricity. The steam is cooled, condensed back into water, and returned to the boiler to start the process over. Burning biomass produces 99 % fly ash, which is very light, exits the boiler along with the hot gases, is removed by an electrostatic precipitator before dispersed into the atmosphere and get to silo to accumulate. TPS fly ash from silo is utilized for improve soil texture and export to foreign country for steel mill industrial.

2.2 Lightweight Concrete

The term of "lightweight concrete" is self-explanation. It is the concrete that has been made lighter than conventional concrete. Normally, it can defined the type of concrete depend up on the its density, e.g. lightweight concrete can be divided into 3 kinds according to the three possible locations of the air void following: in the aggregate particle, which are known as a *lightweight aggregate*; in the cement paste, being known as *cellular concrete*; and between the coarse aggregate particle, the fine aggregate does not use in this kind and call *no-fines aggregate.*(Coad, 1974)

The three kinds of lightweight concrete are shown in the Figure 2.1 and can be seen systematically in Figure 2.2.

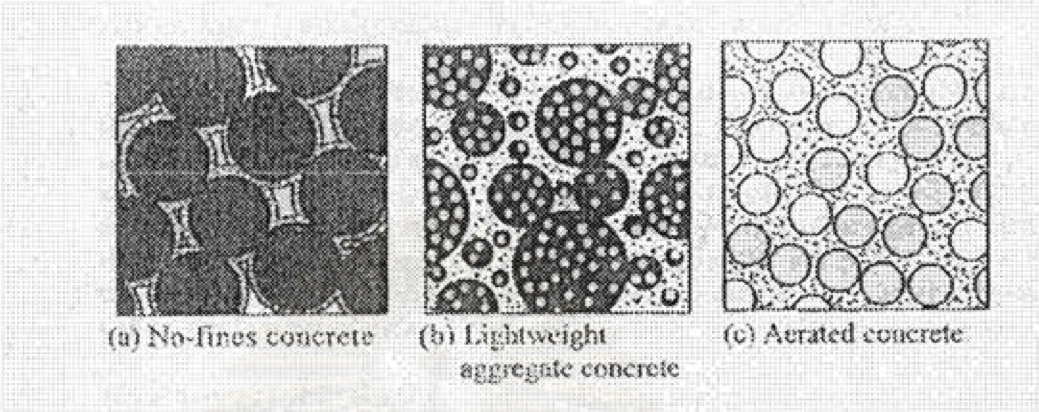

(a) No-fines concrete (b) Lightweight aggregate concrete (c) Aerated concrete

Figure 2.1 Three Basic Type of Lightweight Concrete
Source: Ungsongkhum T. (2005)

However, although there are three distinct types, lightweight concrete can be made which are combinations of three basic types, for example no-fines concrete or aerated concrete containing lightweight aggregates.

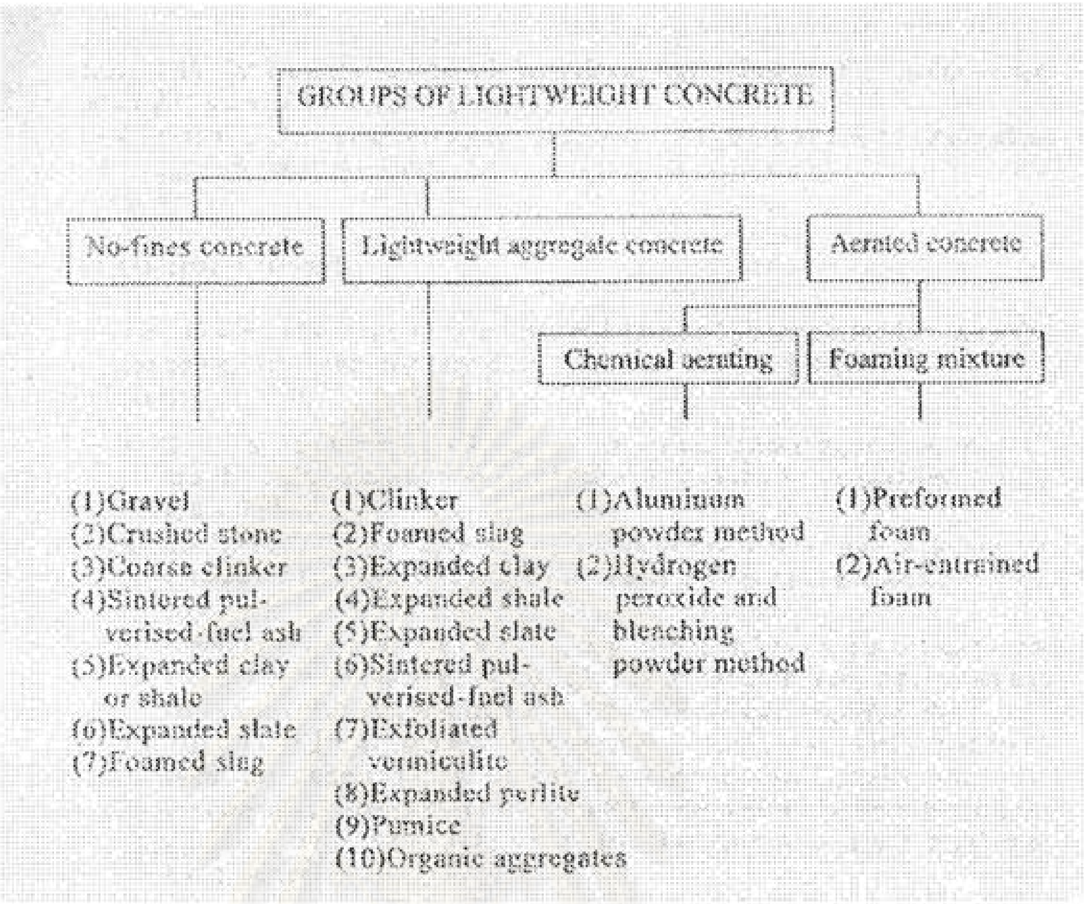


Figure 2.2 Diagrams of Groups of Lightweight Concrete

Source: Ungsongkhum T. (2005)

2.3 Autoclaved Aerated Lightweight Concrete

Autoclaved aerated concrete (AAC) or otherwise known as Autoclaved cellular concrete, is a lightweight. AAC provides structure, insulation and fire resistance in a single which was first developed in Sweden in 1929, it has been refined into the thermally insulating concrete-based materials use for construction both internally and externally. Besides insulating capability, one of AAC's advantages in construction is its quick and easy installation since the material can be routed, sanded and cut to size on site using standard carbon tip band saws, hand saws and drills.

In control factory condition of autoclaved aerated concrete manufacture processes, Cement and/or lime, together with slag, pulverized fuel-ash, sand and/or salacious fine aggregate are used as a raw materials. Air or other gas is introduced into slurry composed of these materials, so that when the mixture sets a uniform, cellular structure is formed

The cell can be formed into the slurry by:

1) Formation of gas by chemical reaction within the mass during the liquid or plastic stage
2) Adding the slurry into the mixture a preformed stable foam or incorporating air by whipping

In genearl, AAC is made from the combination of cement, sand or siliceous material, quick lime, water, and expansion agent. Therefore, many common properties of AAC are influenced by the properties of the cement itself.

ASTM C150 defines Portland cement as hydraulic cement produced by pulverizing clinkers which are the mixture of calcium carbonate in the form of chalk or limestone with aluminum silicates in the form of clay. In the process of cement manufacture, the high temperature of the furnace, the minerals combine to form a clinker composed mainly of calcium silicates and calcium aluminates (Short and Kinniburgh, 1968)[9.18].

The chemical reactions occurring in the cement manufacturing process can be briefly illustrated as the following (Mehta and Monteiro, 1993)[9.11]:

$$\begin{array}{lcl} \text{Linestones} \rightarrow CaO + CO_2 & & 3CaO \cdot SiO_2 \text{ (Tricalcium silicate)} \\ & \Longrightarrow & 2CaO \cdot SiO_2 \text{ (Dricalcium silicate)} \\ & & 3CaO \cdot Al_2O_3 \text{ (Tricalcium aluminate)} \\ \text{Clay} \rightarrow SiO_2 + Al_2O_3 + Fe_2O_3 + H_2O & & 4CaO \cdot Al_2O_3.Fe_2O_3 \text{ (Tricalcium aluminoferrite)} \end{array} \qquad (1)$$

It is customary to express main chemical composition of minerals and the main clinker compounds by using the abbreviations as in the Table 2.2.

Table 2.2 Abbreviations of the Main Composition of Minerals and the Main Compounds of Portland Cement

The chemical composition of minerals	Abbreviation	The main compounds	Abbreviation
CaO	C	$3CaO.SiO_2$	C_3S
SiO_2	S	$2CaO.SiO_2$	C_2S
Al_2O_3	A	$3CaO.Al_2O_3$	C_3a
Fe_2O_3	F	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF
H_2O	H		

In the presence of water, the hydration of Portland cement occurs. The two calcium silicates (C_3S and C_2S) are the main cementations compounds in cement, and the physical behavior of cement during hydration is similar to that of these two compound alone.

The results from hydrations of C_3S and C_2S formation of complex products, Calcium Silicate Hydrate ($C_8S_2H_3$), which referred simply as C-S-H, and the released lime separating our as calcium hydroxide (Ca(OH)2 or CH).The reactions of hydration can be expressed as the following:-

For C_3S:-

$$2(3CaO \cdot SiO_2) + 6H_2O \longrightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + 3Ca(OH)_2$$

or

$$2C_3S + 6H \longrightarrow C_3S_2H_3 + 3CH \qquad (2)$$

For C_2S:-

$$2(2CaO \cdot SiO_2) + 4H_2O \longrightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + Ca(OH)_2$$

or

$$2C_2S + 4H \longrightarrow C_3S_2H_3 + CH \qquad (3)$$

Usually in making Autoclaved aerated concrete by chemical accreting method, aluminum powder is added to the slurry as expansion agent to form air bubbles in the matrix and this reacts with the lime which has been used as the cementing agent or which has been formed in the matrix by the relapsed Lima during the hydration of cement. The formation of bubbles can be simply illustrated in Equation (4).

$$\underset{\substack{\text{Aluminium}\\ \text{powder}}}{2Al} + \underset{\substack{\text{Hydrate}\\ \text{lime}}}{3Ca(OH)_2} + 6\,H_2O \longrightarrow \underset{\substack{\text{Tricalcium aluminate}\\ \text{hydrate}}}{3CaO \cdot Al_2O_3 \cdot 6H_2O} + H_2 \qquad (4)$$

This study will relate with the formation of gas by chemical reaction within the mass be using aluminum powder. Holt and Ravioli (2004), referred that aluminum powder can be abed to the mixing ingredients at about 0.2% to 0.5% by dry weight of cementations. But Mize and Al- Maury (1986), concluded that 0.6% of aluminum powder by weight of dry solids for mixing 60% sand, 30% ordinary Portland cement and 10% lime produce a stable foaming of the wet mixture.

High pressure steam curing is practically unavoidable if aerated concrete is produce with an acceptable level of strength, the reinforcement receives a rust protection prior to casting, but the aerated concrete itself does not contribute to the rust protection of the steel bars. After curing, the product can be further shape in milling machine, and a surface finish can be applied to the factory.

In order to carries out the casting, cutting and steam curing of this materials extensive mechanical equipment, such as moulds, cutting machines, autoclave etc. is required, factory building must also maintain constant atmosphere condition during the casting and curing process. Therefore aerated concrete must be produced under control factory condition, base on the mass production of strictly standardized building unit.

Laukaitis and Fiks (2005), described that there are three kinds of aerated concrete depend upon the matrixes formative of aerated mixtures as following compositions: *gas cement*, water to solid ratio was 0.5-0.7, proportion of blowing agent 0.1-0.25 % of dry solid, lime content 3% of dry solid, and sand to Portland cement ratio 1:1; *gas cement with combined binder,* which has the same content of compositions as previous described of gas cement but differ in 20 % of Portland cement's amount was replaced by lime ; *foam concrete*, water to solid ratio 0.5-0.8, lime content 3 % of dry solid, cement 50 % of dry solid, sand 47 % of dry solid, and foam content(0.2 % of sulfonate solution, and an additive of 0.15 % bone glue) 1.5-3.0 % of dry solid

Ungsungkhun (2005), studied and developed autoclaved aerated lightweight mortar manufacture which is gas cement with combined binder by used as following composition: water to binder ratio 0.5-0.6; blowing content (aluminium powder) 0.4 % of binder's amount; Portland cement 55 % of total solid's amount; and sand 45 % of total solid's amount, but 10 % of Portland cement's amount was replaced by quick lime. And curing was at 160°C by 8 hours.

Phuythamajitt (2006), produced autoclaved aerated lightweight concrete by used as following compositions: water to solid ratio, 60 % of total solid's weight; sand, approximately 30 % of total solid; aluminium content was 0.4 % of binder's amount or 0.27 % of total solid's amount; sand 70 % of total solid's weight; cement 30 % of total solid's weight, but 33 % of Portland cement's amount was replaced by quick lime then, aerated lightweight mortar was curing at 180°C (at the pressure of 20 psi) by 12-14 hours.

Neville (1997), denote that high pressure curing steam or autoclave is curing at high temperature between with 160-210 °C high pressure above atmospheric pressure, and also suggested that a long period of curing at lower temperature, and pressure lead to higher optimum strength than high temperature, and high pressure were applied in shorter time but in general, the detail of curing cycle depend on the size of lightweight concrete.

2.4 The Properties of Aerated Concrete

Density

The density of aerated concrete is within the rang of 300 to 1000 kg/m^3. Thai Industrial Standard Institute (TISI) suggested test method to determine the density as oven-dry density in TIS 1505-1998: Autoclaved aerated lightweight concrete element.

Structure

The structure of aerated concrete is characterized by pores formed by hydrogen gas, air and water at the casting and rising stage. The pores structure is importance for the physical properties of materials such as strength, thermal conductivity, capillarity, frost resistance, etc.

Strength

Strength can be considered in several ways such as compressive strength, tensile strength, shear strength, and so on. But in autoclaved aerated lightweight concrete will focus much on compressive strength, which is a function of density, the compressive strength is somehow lower than conventional concrete due to its own porous structure.

Permeability

The air permeability of aerated concrete decreases with an increases in its moisture content, but even when the concrete is dry, the permeability at low pressure is negligible.

Drying Shrinkage

All cement products show some small change in dimension in response to change in moisture condition. The practical result of shrinkage is the setting up of tension stresses in restrained structures which may lead to cracking. The drying shrinkage of concrete made with lightweight aggregate is generally greater than that of dense aggregate concrete whilst the shrinkage of no-fines concrete is generally lower than that of an all-in aggregate concrete made with the same materials. Precast aerated concrete has a drying shrinkage of about the same as, or perhaps slightly greater than, that of lightweight aggregate but in-situ aerated concrete may have value some five to ten times greater.

Thermal Conductivity

The thermal conductivity of aerated concrete is primary depends on the density. Other factors which affect the thermal conductivity include moisture content, temperature level, raw materials, pore structure.

Resistance Fire

Aerated concrete is non-combustible. Its low thermal conductivity and its equilibrium moisture content make it well suited to protect other structures from the effect of fire

Creep

Creep is influenced by stress level, moisture content, surrounding temperature and relative humidity. An increase of relative humidity results in increase creep. Creep due to these parameters is sorption creep

Sound Absorption

The structure of aerated concrete provides rather better sound absorption than that of smooth, dense concrete.

2.5 Autoclaved Aerated Concrete in Thailand

In 1980, Thailand has more develops in constructions technology, there can found so many high commercial tower, accommodation, public building, and others. And in 1997 autoclaved aerated lightweight concrete was first known and applied underneath Q-con, and Super block brands, they was only used for construction projects of Land & House, and Somprasong Land company Co Ltd., respectively. Due to the outstanding properties of aerated concrete as previously described made a higher tendency of demand and was in short supply in 2002. Nowadays, there were about 8 companies of autoclaved aerated lightweight concrete manufacture in Thailand in order to satisfy the rising of accommodation demands with totally capacity approximately 2.25 million m^3 per year.

Case study:

Q-Con

Quality Construction Product Public Co., Ltd. Or Q-Con located at Ayutthaya province, Thailand, is a famous manufacturing the autoclaved aerated concrete products. Q-Con took manufacturing processes from Hebel International GmbH&Co. from Germany since 1995

Q-Con autoclaved aerated concrete is produce in block, reinforced panel, lintel, mortar, tool, and accessories for use in both housing and commercial construction and suitable for load bearing and none load bearing application. It need to revolutionary materials that offer unique properties no matter, strength, low density, thermal insulation, and fire resistance

The average density of autoclaved aerated concrete in market is present at 500 kg/m^3, this density is less than normal weight concrete about four times and less than two or three times when compare with masonry block. Furthermore, Q-Con autoclaved aerated concrete block (200x600x100mm^3) can bear the maximum load up to 22 tons.

Super Block

Super Block Ltd., is Thai company under BOI promotion programmed and located in SinghBuri province, Thailand. Super Block are licensed to produce commodity block from Y-Tong and Wehrhahn 2 in Germany since 1995

Super block is manufacture from combine lightweight materials with high strength and provide some advantages over other building materials such as thermal insulation, acoustic dampening, and fire resistance.

Super block is manufacture from cement, lime, and sand which are obtained from local area, and mix water and then, aluminium powder is added, which is only material imported. After setting, to make the smaller size from large mould block by using precision mechanic steel wire culling system then, curing at high pressure steam for 24 hrs.

Whereas compare with clay bricks the density of Super block (550 kg/m^3) is less than to 2.5 times and its compressive strength approximately 5 N/mm^2

2.6 The Using of Fly Ash as Main Ingredient in Concrete

The term fly ash is often used to describe any fine particulate precipitated from the stack gases of industrial burning solid. The amo9unt of fly ash collected from furnaces on a site can vary from less than one ton pre day to several tons per minute.

The characteristics and properties of different fly ashes depend on the nature of the fuel and the size of furnace used. Pulverization of solid fuels for the large furnaces used in power stations creates an immediate, urgent problem; dry ash has to be collected from the stack gases and disposed of quickly. The similarity of some fly ashes to natural of volcanic origin has encouraged the use of fly ash in conjunction with Portland cement in concrete making. Not all fly ashes are suitable for this application, however; unstable chemical reactions may have adverse effects on both the hydration process and the ultimate stability of the end product.

Due to low-calcium fly ashes usually contain quartz, mullet, hematite and magnetite, while high–calcium ashes contain quartz, lime, mullite, gehlenite, and anhy–drite and cement minerals such as C_3S and C_2S. Both types of fly ash have pozzolanic properties, but high–calcium fly ashes also exhibit cementations properties. Owing to these differences. The interactions of each of these two types with cement require separate consideration (Wesche, 1991).

Pozzolan are siliceous or siliceous and aluminous which, though them-selves possessing little or no cementations value, will, in finely divided from and in the presence of moisture, react chemically with calcium hydroxide at ambient temprematuree to from compounds with cementations properties (ASTM Standard C 618-80)

Fly ash is a solid, fine-grained material resulting from the combustion of pulverized coal in power station furnaces. The material is collected in mechanical or electrostatic separators. The term fly ash is not applied to the residue extracted from the bottom of boilers.

Fly ashes capable of reacting with Ca (OH)2 at room temperature can act as pozzolanic materials The pozzolanic reaction can be written as the following:

$$\underset{\text{Calcium Hydroxide}}{3Ca(OH)2} + \underset{\text{Pozzolan}}{2SiO_2} \longrightarrow \underset{\substack{\text{Calcium Silicate Hydrate}\\ \text{(C-S-H)}}}{3CaO \cdot 2SiO_2 \cdot 3H_2O} \qquad (5)$$

Their pozzolanic activity is attributable to the presence of SiO_2 and Al_2O_3 in amorphous from.

Fly ashes may be sub-divided into two categories, according to their origin (ASTM):

Class F: Fly ash normally produced by burning anthracite or bituminous coal which meets the requirements applicable to this class. Class F fly ash has pozzolanic properties.

Class C: Fly ash normally by burning or sub- bituminous coal which meets the requirements applicable to this class. In addition to pozzolanic properties, class c fly ash also possesses some cementations properties. Some class C fly ashes may have lime contents in excess of 10%

Gunawan (2006), studied on the using of pulverized coal fly ash to replaced 10 % of Portland cement's amount in aerated lightweight mortar resulted on possessed the compressive strength about 40 % higher than control mix proportion.

Peamchad et, al.(2005), studied on the utilization of lignite and rice husk fly ash as a partial replacement of Portland cement in light block concrete (foam concrete), by replacing of 15% of cement's used, the results denoted that the compressive strength was decreased as the particle size of fly ash decreased, the mix of rice husk fly ash replacing cement resulted in lower strength than coal fly ash replacement about 40 percent.

Ungsungkhun (2005), found that the used of pulverized coal fly ash as a cement rep[lacing up to 60 % in autoclaved aerated lightweight mortar , it retarded the initial and final setting times, decreased water to cement ratio, and decreased density of mortar but increased the value of desire water absorption at the same consistency.

Behera, and Sarangi (2004), studied in lightweight concrete with sintered fly ash from coal combustion as partial replacement normal granite aggregate up to 40 % by weight, the compressive strength less than norm concrete < 1%. However, the density of lightweight concrete still higher than desire value.

CHAPTER III

RESEARCH AND METHODOLOGY

3.1 Materials

3.1.1 Portland Cement

Portland cement type I as specified in TIS 1505-2541 (1998) was used as a binding material throughout the experimentally. This is the most common cement used in general concrete construction which there is no exposure to sulphates in the soil and water

3.1.2 Quick Lime

Quick lime or calcium oxide (CaO) according to TIS 319 is a white solid was used as another binding material to increase the rate of hardening and to react with aluminum powder during the hydration of cement in order to introduce hydrogen gas.

3.1.3 Fly Ash

In this study, Fly ash was obtained from Thai power supply (TPS) Co., Ltd. in Chachoengsao province, Thailand. Three batch of biomass fly ash from burning process of three biomass feed recipes as shown in Table 3.1 were used in this program.

Table 3.1 The Recipes of Biomass Feed Recipes

Type of biomass	**Rice husk**	**Coal**	**Wood chip**	**Corncob**	**Sawdust**	**Palm resident**
Rice husk(RH)	100%	0%	0%	0%	0%	0%
Biomass feed recipe #3(B3)	16%	11%	53%	17%	3%	0%
Biomass feed recipe #4(B4)	8%	23%	64%	0%	0%	5%

3.1.4 Fine Aggregate

Natural river sand passing sieves No.65 and retained on the sieve No.100 was used as a fine aggregate to make lightweight concrete for all mixes.

3.1.5 Blowing Agent

Aluminum powder is fine and silvery power; it was used as blowing agent which was react with calcium hydroxide ($Ca(OH)_2$) to produce hydrogen gas.

3.1.6 Water

Ordinary tap water was used throughout the experimental program

3.2 Experimental Program

The experimental program was divided into three parts, which was illustrated in Figure 3.1, the first part dealt with the physical and chemical properties of the materials while the second part explored the optimum curing period, aluminium content, water-to-binder ratio, and binder-to-aggregate ratio suitable for lightweight concrete. Subsequently, the final part was conducted to obtain the optimum mix proportion of the substituted biomass fly ash by comparing the physical and mechanical properties of lightweight concrete test samples; namely, density, compressive strength, and desired water absorption.

3.2.1 Study on Physical and Chemical Properties of Lightweight Concrete Main Materials

Table 3.2 The Methodology for Analyst Physical and Chemical Properties of Fly Ash

Parameters	**Standard and analyzer**
Moisture content	ASTM D 2216-98
Loss on ignition (LOI)	ASTM D7348-07
Particle size distribution	ASTM D5158-98(2005)
Bulk specific gravity	ASTM C 128-93
Chemical composition	XRF
Amorphous structure	XRD

3.2.1.1 Loss on Ignite (LOI)

Loss on ignite (LOI) is normally used to represent the carbon content in the sample since carbon content will reduce the air entrainment presented in the concrete that effect the workability, strength, durability of concrete. Consequence, the higher carbon contents could adversely affect the performance of concrete. LOI is defined by ASTM C311 as the weight fraction, expressed as percentage, of material that is lost by heating the oven-dried sample at 750 ± 50°C. LOI is a measurement of unburned carbon remaining in the ash. It can be used as important indicator of the degree of burnout in materials or combustion efficiency.

3.2.1.2 Particle Size Analysis

In this study, all three biomass fly ash and Portland cement were subjected to particle size analysis by Malvern Particle Size Analyzer model Masterizer 2000 equipped with the Scirocco 2000 that measures particle size ranging from 0.02-2000 microns

Particle size of cement and binder has a significant effect on the hydration reaction rate. Finer particle cause reduction in setting time and increase the compressive strength development due to it has more specific surface area to react with water than coarser particles.

The size distribution of particle in the waste often indicated the potential for water movement through the material and compressibility. Also very fine grained materials have been shown to produce poorly stabilized material. Presence of large particles may be required the use of size reduction equipment. The best material for forming a strong interlocking matrix is well graded, with few particles in extreme sizes.

3.2.1.3 Bulk Specific Gravity

Bulk specific gravity depends on its physical properties and chemical compositions. It is defined as the ratio of weight of a given volume of a sample to the weight of an equal volume of water. It is used to design the mixture proportion of concrete. Unit weight of concrete product is also depending on the specific gravity of its mixture. Specific gravity provides an indication of the material, voids in the particles and existence of non-combusted materials.

3.2.1.4 Chemical Compositions Analysis by XRF

ASTM C618 list the required chemical composition for coal fly ash used in concrete. These limitations are base on oxide of silica, aluminium, calcium, sulfur, and iron. Silica and aluminium silicate are the major composition in the pozzolanic reaction, while sulfur and alkali have the adverse on the effect of durability of concrete. X-ray fluorescence spectrometer Philips PW 2400 was used to determine the elemental composition of biomass fly ash in this study.

To obtain a good representative, firstly, a sample was grounded in the ceramic mortar to homogeneously fine powder (size was below 45 microns) due to the X-ray only penetrates up to a few millimeters from surface of sample. After that, 1.5 grams of H_3BO_3 (2.5% by weight) binder, was mixed approximately 4.5 grams of grinded sample and binder was press into the pellet for convenient handling and measurement. The pilled sample was put in the sample cup. Each sample would take 30 minutes for the instrument to detect characteristic X-rays of elements emitted from the sample in helium environment.

3.2.1.5 X-Ray Diffraction spectrometer

X-ray Powder Diffraction (XRD) is an efficient analytical technique used to identify and characterize unknown crystalline materials. Monochromatic x-rays are used to determine the interlunar spacing of the unknown materials. The x-ray spectra generated by this technique, thus, provide a structural fingerprint of the unknown. Mixtures of crystalline materials can also be analyzed and relative peak heights of multiple materials may be used to obtain semi-quantitative estimates of abundances. A glancing x-ray beam may also be used to obtain structural information of thin films on surfaces. In addition, changes in peak position that represent either compositional variation (solid solution) or structure-state information (e.g. order-disorder transitions, etc.) are readily detectable. Peak positions are reproducible to 0.02 degrees. In this research, the analyzer was used to determine the crystal type of raw biomass ash.

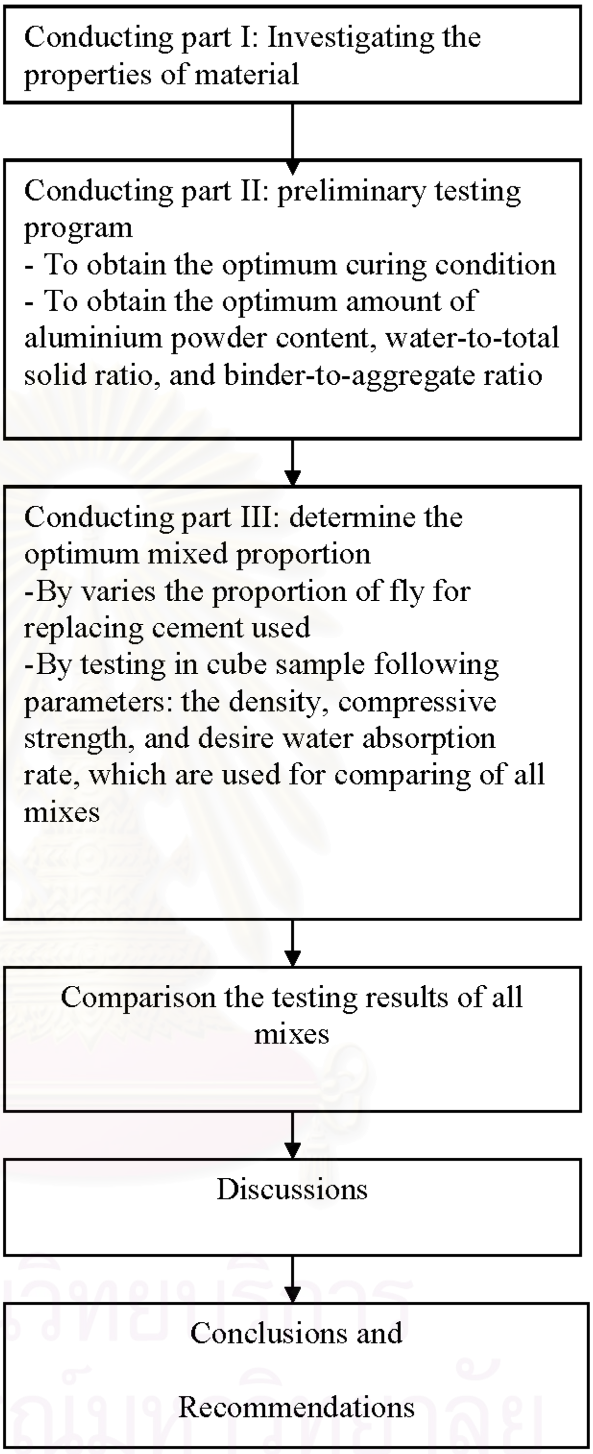


Figure 3.1 Flow Chart of Experimental Program

3.2.2 Preliminary Testing Program

This part dealt with preliminary testing which was about determining the suitable curing time, the optimal aluminium powder content, optimal binder-to-aggregate ratio, and water-to-solid ratio. Firstly, to obtain the optimum curing period of high pressure curing steam, the several curing condition was conducted experimentally under the same proportion as following compositions: cement, 55% of total solid's amount; sand, 45% of total solid's amount; 10% of Portland cement was replaced by quick lime; aluminium powder content, 0.36% of binder's amount or 0.20% of total solid's amount; and water to binder 0.26, shown in Table 3.3. The curing period of time was varied from 10, 12, 14, and 16 hours. To achieve the proper curing time for this study the compressive strength was investigated and compared for all mixes.

Table 3.3 Mix Proportion to Determine the Suitable Curing Duration

Compositions	**Amount (%)**	
1.binder	55	
1.1Quick lime		10% of binder
1.2Cement		90% of binder
1.3 Fly ash		0
2.sand	45	
3.Aluminium powder	0.2	
4.water	0.26 of W/TS ratio	

Subsequently, the testing program to find the optimum value of aluminium powder content, proportion of binder to aggregate ratio, and appropriate water to total solid ratio. Twenty seven trial mixes was conducted the experimentally. To start the investigation, the proportion binder to aggregate was 60:40 by 10% of Portland cement's amount was replaced by quick lime, the content of aluminium amount was varied from 0.20%, 0.25%, and 0.30% of total solid's amount, and each trial mixes was varied water to total solid ratio from 0.28, 0.31, and 0.34 Then, the proportion of binder to aggregate ratio was changed from 60:40 to 55:45, and 50:50 but the content of aluminium powder, and water to solid ratio was the same varied as 60:40 binder to aggregate proportion as shown in Table 3.4. To obtain the optimum proportion of binder to aggregate ratio, amount of aluminium content, and water to aggregate ratio, the density, and compressive strength was determined and compared for all mixes.

Table 3.4 Details of Mix Proportion for Determining the Optimal Aluminium Powder Content, Water-to-Total Solid Ratio, and Binder-to-Aggregate Ratio

No.	No. of specimen	Compositions			
		Dry Solid		Al powder (%)	Water-to-Total solid (%)
		Binder	Sand		
1	18	50	50	0.20	0.26,0.29,0.32
2	18	50	50	0.20	0.26,0.29,0.32
3	18	50	50	0.20	0.26,0.29,0.32
4	18	55	45	0.25	0.26,0.29,0.32
5	18	55	45	0.25	0.26,0.29,0.32
6	18	55	45	0.25	0.26,0.29,0.32
7	18	60	40	0.30	0.26,0.29,0.32
8	18	60	40	0.30	0.26,0.29,0.32
9	18	60	40	0.30	0.26,0.29,0.32

3.2.3 Main testing program

After the preliminary testing program, the main testing was carried out. The results from preliminary testing were used in main testing program. The two parameters namely, Portland cement and biomass fly ash content was investigated under the laboratory test to achieve the optimum mix proportion by all mixes based on density, compressive strength, and water absorption. At this stage was a series of mixes, the amount of fly ash replacing was varied from 0%, 5%, 10%, 15%, 20%, 25%, 30%, and 40% of Portland cement use, and used the same variation as previously mentioned for all of three different recipes of biomass fly ashes.

3.3The autoclaved aerated lightweight concrete manufacture process

Under the laboratory conditions, the siliceous material; sand, cement, fly ash, aluminium powder, quick lime was weigh by digital weighting machine. The siliceous materials were mixed together with quick lime which was combined to cement and fly ash. After all of solid was introduced in the mixer, then water and blowing agent were added. Subsequently, the slurry was cast into 2-in cube moulds to about ¾ full and vibrated. Leave the slurry rise into exceed the top of the moulds, and set, and then removed the excess amount from the top of the moulds to desirable shape while it stills soft. After removing the mould, the 2-in cube specimens were cured in an autoclaving under high pressure steam curing. Finally, the specimen was moved from an autoclave machine and ready for the next test program.

3.4 Physical and mechanical properties testing program

In this program, the investigation properties of the 2-in cube test sample were done. After the period of under high pressure steam curing in an autoclaving, the testing samples were allowed to dry at temperature. The investigation consist with the parameter namely the density, the compressive strength, and the desire water absorption according to TISI standard.

3.4.1 Desired Water Absorption

The 2-in cube samples were immersed in the water by 24 hours to achieve a saturate condition according to the TISI standard; TIS 1505-2541 (1998). After 24 hours period of immersion, the cube samples were allowed to drain and wiped off to obtain saturated surface dried condition, and then test samples were weighed and recorded. Subsequently, the testing samples were dried in the oven at 105 ± 5 °C for 24 hours. After that the cube samples were allowed to cool down at room temperature, and then the testing samples were weighed and recorded. The water absorption is the ratio of the different in 2-cube samples weight between the saturated surface-dried weights in percent.

3.4.2 Density

The 2-in cube samples were dried in the oven at 105 ± 5 °C for 24 hours. After 24-hours the 2-in cube samples were allowed to cool down at room temperature then were weighed and recorded. The density of samples is the weights after dried in oven divide by volume of 2-in cube samples in unit of kg/m^3

3.4.3 Compressive strength

The 2-in cube test samples were measured and recorded the dimensions according to the TISI standard; TIS 1505-2541 (1998). Then the test samples were placed into the testing machine and load were applied perpendicularly to the direction of rising force, the maximum load at which the specimen samples fail were recorded. The compressive strength is the failure load of each specimen samples divide by the area over the load.

CHAPTER IV

RESULTS AND DISCUSSION

The results presented in this chapter were based on the series of experiments conducted during the course of this study. The test results could be provided into three parts. The first part dealt with the physical and chemical of constituent raw materials of lightweight mortar. The second part was concerned with preliminary testing designed to determine suitable curing time, optimal aluminium powder content, optimal binder-to-aggregate ratio, and water-to-total solid. Subsequently, the final part was conducted to achieve the optimal mix proportion by all mixes based on the physical and mechanical properties of lightweight concrete.

4.1 Physical and Chemical properties of the Materials

Utilization of raw materials as a natural pozzolan in construction application is primarily dependent on their physical, mechanical, and chemical properties (Wesche, 1991). Currently, the pozzolan used are commonly by product materials that are widely available, fly ash, is the most extensively use material, is an inorganic, noncombustible from combustion process in power plant. Due to fly ash are such diverse materials, it would be expected overall physical and chemical properties would be quite variable as well. For this study, the replacing materials called fly ash were obtained from three biomass feed recipes of biomass power plant (TPS Co., Ltd.) as previous mentioned in Table3.1, were methodically evaluated with following parameters that cited in Table3.2.

4.1.1 Moisture Content

The combined water of materials can be evaluated by determination of moisture content of the material. The value of moisture content more than 3%, it means that there is a lot of combined water in the material and compromise on water-to-cement ratio. Eventually, it has effect to the compressive strength of concrete. Moisture content of rice husk fly ash (RH), fly ash of biomass feed recipes # 3(BFR#3), and fly ash of biomass feed recipe # 4 (BFR#4) was 0.0828, 1.4964, and 1.4483 respectively. Thus, it denoted that the combined water in all three kinds of fly ash lied in acceptable value according with ASTM C618 standards.

4.1.2 Loss on Ignite (LOI)

Based on ASTM D7348-07, LOI value of rice husk fly ash, fly ash of biomass feed recipes # 3, and fly ash of biomass feed recipe # 4 was 4.25, 5.06, and 6.11%, respectively. As previous mentioned in chapter 2, LOI is mainly used to determine the carbon content in the sample. LOI value more than 6-10 % in fly ash will increase water adsorption value in concrete due to the intrinsic porosity structure of carbon molecules resulting on negative effect on workability, strength, and durability of concrete (Jindaprasert, 2004). In addition, high carbon content has also effect to chemical additive of concrete.

According with ASTM C618-96, classification for pozzolanic material, the maximum LOI value was 10, 6, and 6% for pozzolanic class N, F, and C respectively. But Jindaprasert (2004) also denoted that pozzolanic material class F could has LOI value up to 12% when other properties of fly ash corresponded with the requirement in F class.

4.1.3 Specific Surface Area and Particle Size Distribution

Pozzolan materials must be in finely divided state to be effective. Most natural materials require grinding to cement fineness. A more useful parameter is the surface area, since the rate of pozzolanic reaction will be proportional to the amount of the surface available for reaction (Mindess, 2003). A comparison of specific surface area of materials was given in Table 4.1.

Beside, the surface area of material is related to its mean particle size is a consequence of it cellular nature and is a reason for its high reactivity. Therefore, in this study, complete particle size distribution analyses of materials were conducted. The particle size distribution diagrams of three pulverized biomass fly ash and Ordinary Portland Cement were shown in Figure 4.1, Figure 4.2, Figure 4.3, and Figure 4.4, respectively. And the comparison of particle size of all materials at 50% and 90% accumulative volume that were cited in Table 4.1. From the results, it can be noted that both specific surface area and mean particle size for these fly ash were in nearly value as compared with Portland cement.

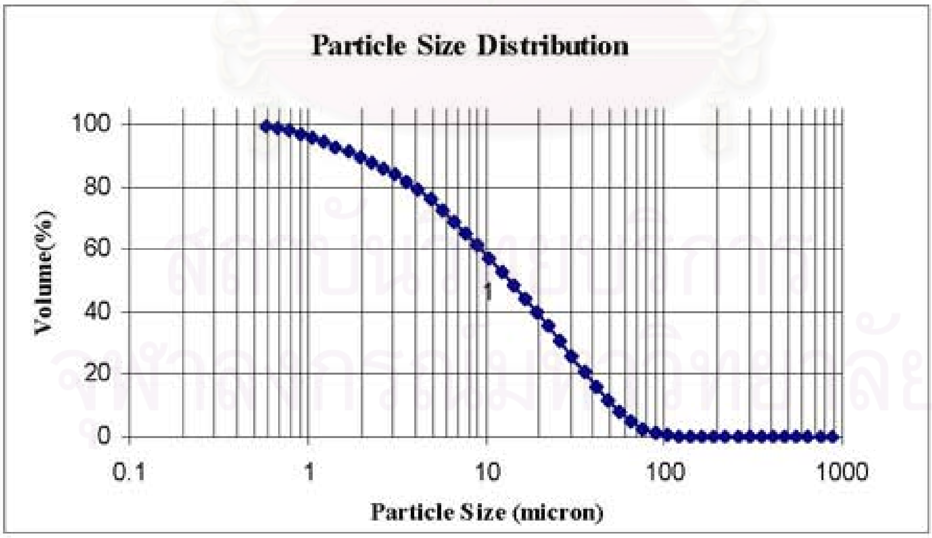


Figure 4.1 Particle Size Distribution of pulverized rice husk fly ash

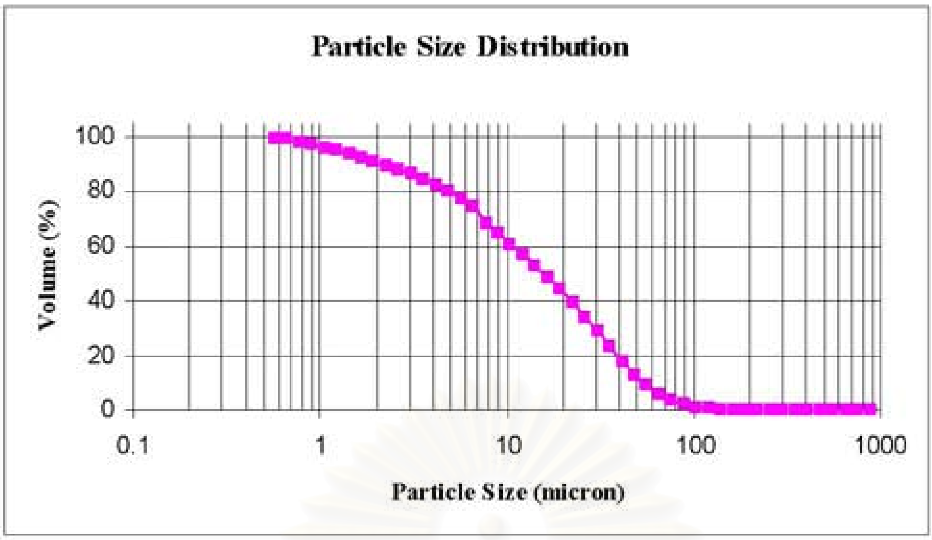


Figure 4.2 Particle Size Distribution of pulverized BFR#3 fly ash

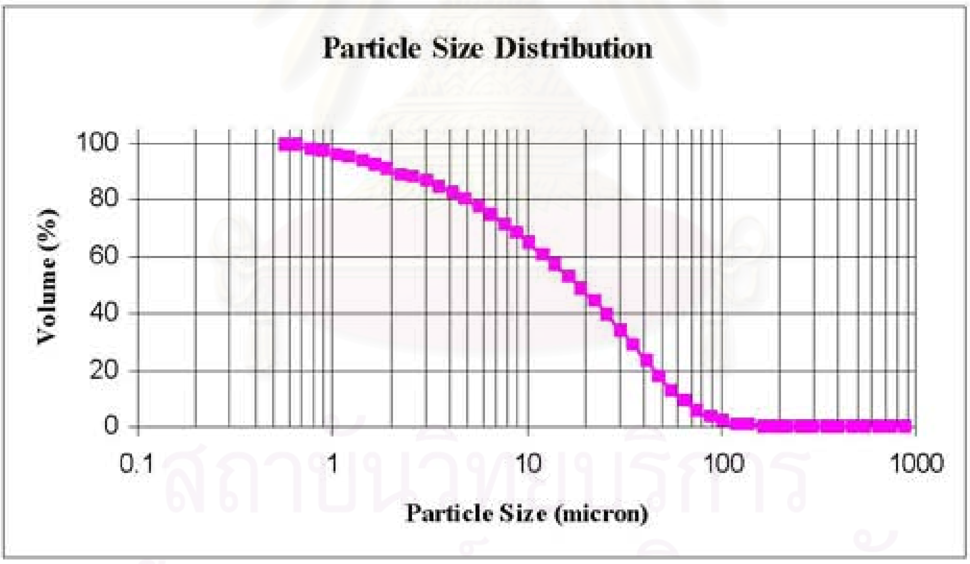


Figure 4.3 Particle Size Distribution of pulverized BFR#4 fly ash

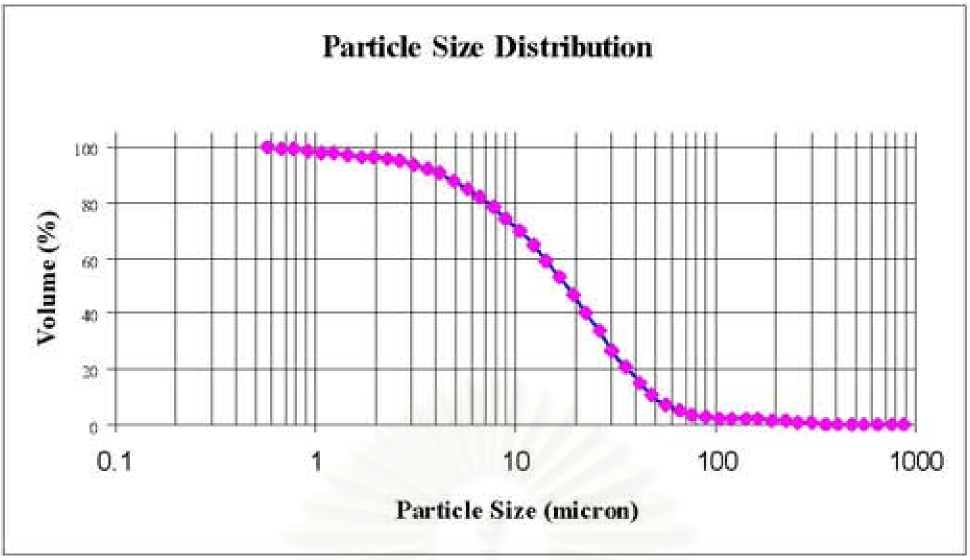


Figure 4.4 Particle Size Distribution of Cement

Table 4.1 Particle Size and Specific Surface Areas of Pulverized Fly ash, Portland Cement, and Fly Ash (F and C)

Materials	d $_{50\%}$ (Microns)	d $_{90\%}$ (Microns)	Specific Surface Area** (M^2)
Portland cement	20.14	63.2	<1
Flash (F and C)	10-15**	NR	1-2
Rice husk	13.16	49.73	50-100
Biomass feed recipe # 3	18.42	63.50	NR
Biomass feed recipe # 4	20.14	89.50	NR

** Mindless, young, and Darwin (2003)

NR reoffered to not report.

4.1.4 Bulk Specific Gravity

Bulk specific gravity can be used to preliminary chemical composition, non-combustible material, void and fineness of the material. Furthermore, it is significant in designing the mix proportion and unit weight of concrete. In Table 4.2, it shown a comparison of bulk specific gravity of three biomass fly ash, Portland cement, and sand are tabulated.

Table 4.2 Bulk Specific Gravity of Pulverized Biomass Fly Ash versus Portland Cement

Materials	Bulk Specific gravity
Rice husk	2.22
Biomass feed recipe # 3	2.24
Biomass feed recipe # 4	2.38
Cement	3.05

From the results, it can be seen that the bulk specific gravity of three biomass fly ash was significantly lower than Portland cement. As shown in Table 4.2, due to the fact that these three biomass fly ash were higher specific surface Area than Portland cement. Moreover, the intrinsic chemical compositions were different resulting in bulk specific gravity of each one has different that is, Portland cement contains high amount of CaO, Al_2O_3, and Fe_2O_3 which actually high bulk specific gravity. On the Country, the main constituent in these fly ash were SiO_2 that low bulk specific gravity accorded to the chemical compositions were shown in Table 4.3. From those results, it can be concluded that rice husk fly ash which was the highest amount of SiO_2 then, it had possessed the lowest bulk specific gravity as compared with of other biomass fly ash and Portland cement. For fly ash resulting from BFR # 3, it was the highest value of specific gravity that might be due to it contained the highest amount of CaO and Al_2O_3 as compared with other ones.

4.1.5 Chemical Composition

Chemical composition of material can be used to predict the behavior and properties of the material in the environment as well as its applications. For example, it could have a negative effect on reinforced steel in concrete when the materials contain high chloride content and it also increase the ability of metal to leach into the environment (Rachakornkij, 2000). The chemical composition of fly ash, RH, BFR#3, and BFR#4 was determined by X- ray fluorescence (XRF) which is provided in oxide form as illustrated in Table4.3. After burning in boiler biomass become biomass fly ash. Most components of biomass were burnt and volatized, thus, the main compositions of biomass fly ash were inorganic substances and metal ions. The results shown that the main constituent, silica, measured at, 88.09%, 73.82%, and 59.67% by weight of FA, BFR# 3, and BFR#4, respectively.

A comparison with Portland cement was also made in the same Table. It can be observed that the silica content of Portland cement was lower than fly ash from three biomass feed recipes but calcium content was higher than fly ash from three biomass feed recipes pretty much. For other compositions, there lied in the same range with that fly ash.

Table4.3 Chemical Composition of Fly Ash from Three Biomass Feed Recipes and Portland Cement

Compositions	**Rice husk (RH)**	**Biomass feed recipe#3 (BFR#3)**	**Biomass feed recipe#4 (BFR#4)**	**Portland cement***
Na_2O	0.07	0.19	0.31	NR
MgO	0.50	1.10	1.60	0.1-0.4
Al_2O_3	0.19	0.50	7.89	3-8
SiO_2	88.09	73.82	59.67	17-25
P_2O_5	1.17	1.43	1.73	NR
SO_3	0.25	0.78	1.76	1-3
Cl	0.44	2.09	0.87	NR
K_2O	3.20	4.84	3.99	NR
CaO	0.78	7.10	9.29	60-67
TiO_2	0.00	0.06	0.47	NR
MnO	0.24	0.33	0.30	NR
Fe_2O_3	0.22	0.79	3.92	0.5-6.0

* Ruangchuary, 2005

NR referred to not reported

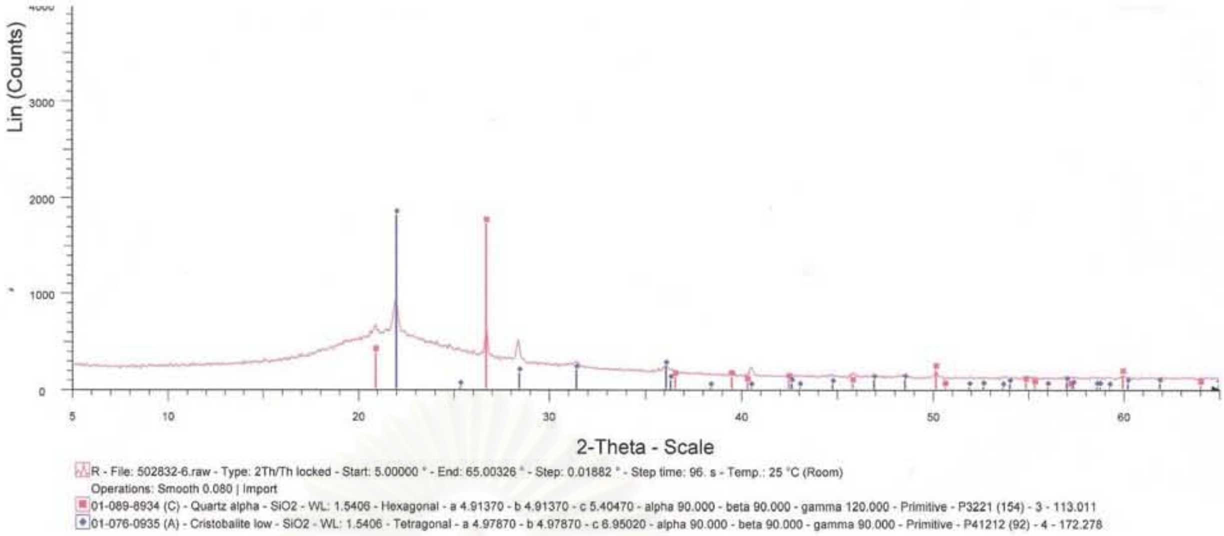
Fly ash resulting from three biomass feed recipes was generated from the combustion process. The burning condition should have differed from one firm to another somehow. Subsequently, the chemical compositions for fly ash from any firms may vary as well. Base on ASTM C618-96, classification of fly ash resulting from three biomass feed recipes as a pozzolan was compared in Table 4.4. It can be denoted that fly ash resulting from three biomass feed recipes fit F-class since they contain more than 70% of the sum of silica (SiO_2), alumina (Al_2O_3), and calcium (CaO). Moreover, sulfur (SO_3), magnesium (MgO), and sodium (Na_2O) content of fly ash also met the ASTM standards.

Table 4.4 Comparison of Chemical Properties of Fly Ash Resulting from Three Biomass Feed Recipes versus ASTM Requirement for a Pozzolan

Properties	**Pozzolan class**			**RH**	**BFR#3**	**BFR#4**
	N	**F**	**C**			
SiO_2+Al_2O_3+Fe_2O_3, min	70.0	70.0	50.0	89.1	81.4	76.9
SO_3, max	4.0	5.0	5.0	0.3	0.9	1.8
MgO, max	5.0	5.0	5.0	0.5	1.1	1.6
Na_2O, max	1.5	1.5	1.5	0.1	0.2	0.3

4.1.6 Amorphous Structure

Even though, chemical compositions can give some idea about the feasibility of using fly ash as a pozzolan material, the information on the structure of material is really important as well. In general, silica will responsible for the compressive strength of concrete by pozzolanic reaction between calcium hydroxide ($Ca(OH)_2$) and silica and hydration of silica itself (Singh et al., 2000) but just only silica was in amorphous form (Davraz and Gunduz, 2005).For this experiment, the amorphous structure of fly ash resulting from three biomass feed recipes was studied by X-ray diffraction (XRD). From XRD pattern which cited in Figure 4.5. It indicated that silica was in poorly amorphous form that is one of reactive form of natural pozzolan materials. From the results, it can be used to note that the fly ash from three biomass feed recipes could be used as pozzolan material in construction application.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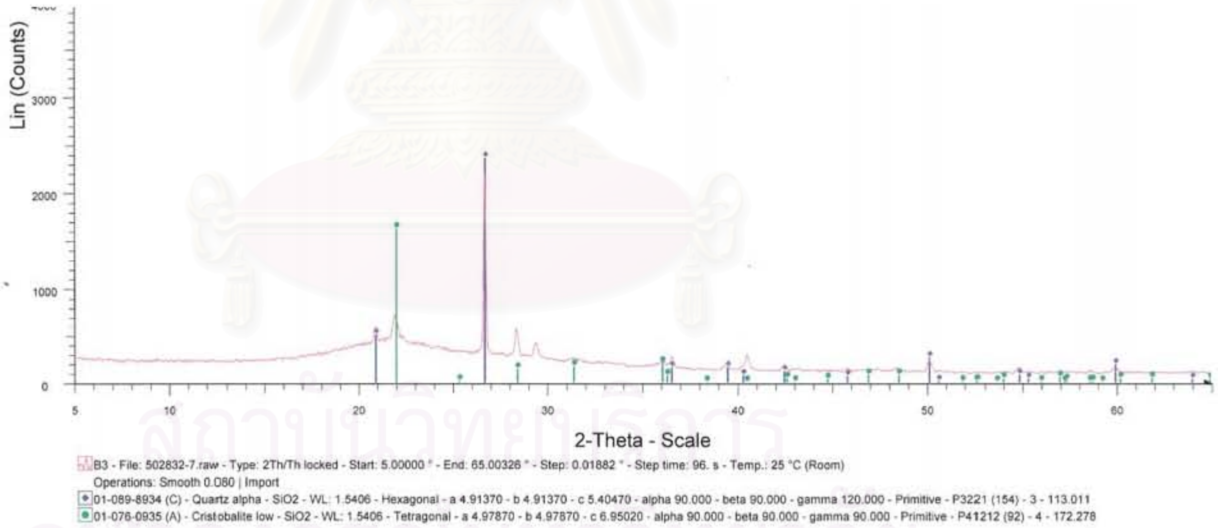
2-Theta - Scale
R - File: 502832-6.raw - Type: 2Th/Th locked - Start: 5.00000 ° - End: 65.00326 ° - Step: 0.01882 ° - Step time: 96. s - Temp.: 25 °C (Room)
Operations: Smooth 0.080 | Import
01-089-8934 (C) - Quartz alpha - SiO2 - WL: 1.5406 - Hexagonal - a 4.91370 - b 4.91370 - c 5.40470 - alpha 90.000 - beta 90.000 - gamma 120.000 - Primitive - P3221 (154) - 3 - 113.011
01-076-0935 (A) - Cristobalite low - SiO2 - WL: 1.5406 - Tetragonal - a 4.97870 - b 4.97870 - c 6.95020 - alpha 90.000 - beta 90.000 - gamma 90.000 - Primitive - P41212 (92) - 4 - 172.278

(a)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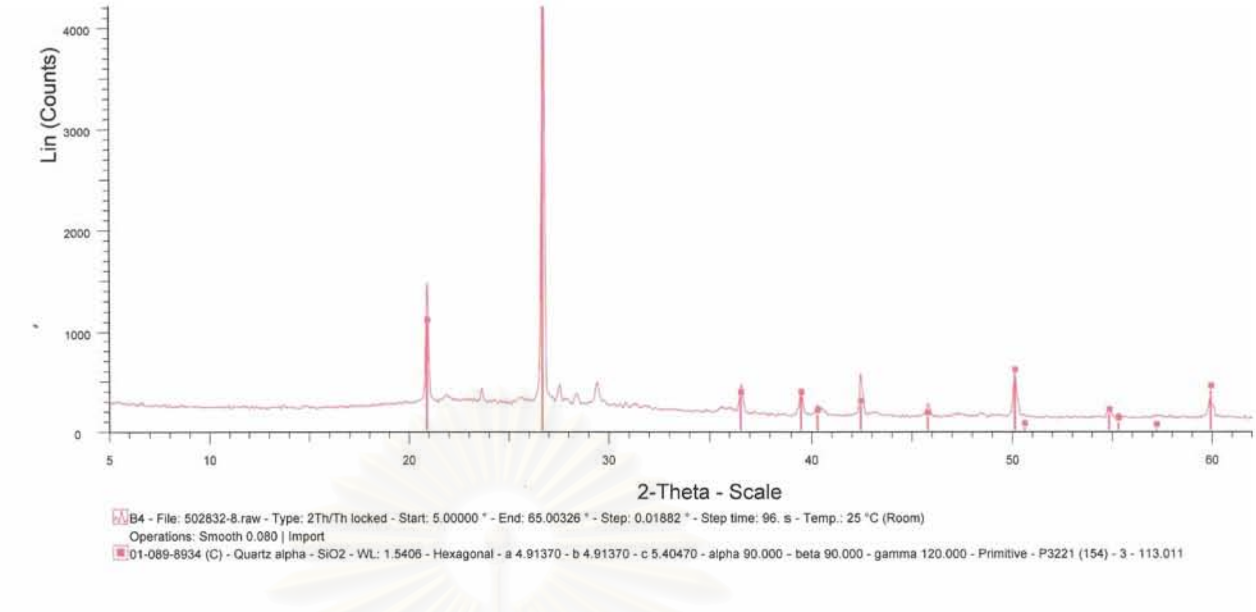
2-Theta - Scale
B3 - File: 502832-7.raw - Type: 2Th/Th locked - Start: 5.00000 ° - End: 65.00326 ° - Step: 0.01882 ° - Step time: 96. s - Temp.: 25 °C (Room)
Operations: Smooth 0.080 | Import
01-089-8934 (C) - Quartz alpha - SiO2 - WL: 1.5406 - Hexagonal - a 4.91370 - b 4.91370 - c 5.40470 - alpha 90.000 - beta 90.000 - gamma 120.000 - Primitive - P3221 (154) - 3 - 113.011
01-076-0935 (A) - Cristobalite low - SiO2 - WL: 1.5406 - Tetragonal - a 4.97870 - b 4.97870 - c 6.95020 - alpha 90.000 - beta 90.000 - gamma 90.000 - Primitive - P41212 (92) - 4 - 172.278

(b)



(c)

Figure 4.5 XRD pattern of fly ash resulting from three biomass feed recipes (a) Rice husk (b) Biomass feed recipe #3 (c) Biomass feed recipe #4

4.2 Test results of Preliminary Testing Program

4.2.1 Appropriate Curing process

The compressive strength of lightweight 50 mm. cube test mortar with the same mix proportion at 1 day after curing at high pressure steam and temperature and subjected to four different curing duration that was varied from 10, 12, 14, and 16 hours under were shown in Figure 4.6.

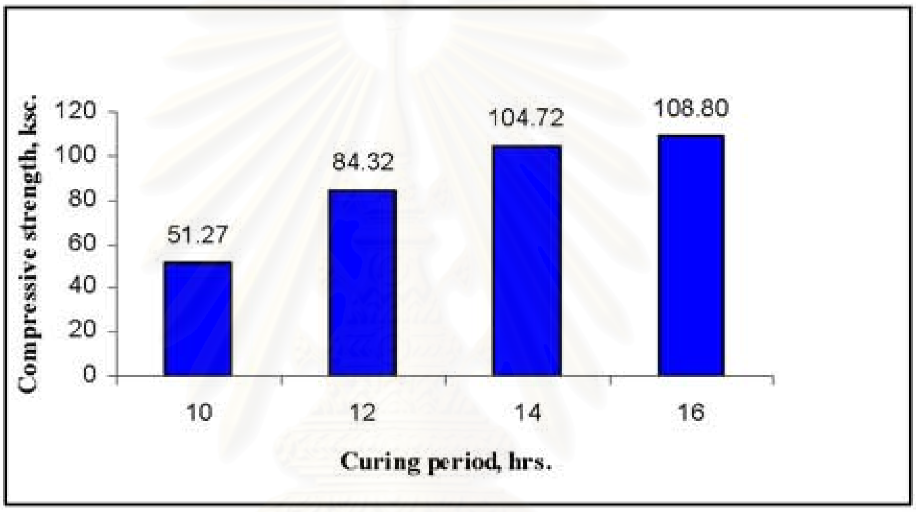


Figure 4.6 Compressive Strength at 1 Day Age of Lightweight Concrete Subjected to Various Curing Periods

From the comparison of compressive strength of lightweight mortar subjected to four curing periods, it can be denoted that the compressive strength of lightweight mortar related with curing duration, a longer period of curing led to higher compressive strength of lightweight concrete at the same age and mix proportion As shown in Fig 4.6, the curing period of 10 hours resulted in the lowest compressive strength, while curing period of 14, and 16 hours gave the highest compressive strength of lightweight concrete without significant different. This found was corresponding with Neville (1997) mentioned about suitable curing duration involved with the size of concrete specimen, temperature, and pressure that were applied from case by case. Thus, the high pressure curing period of 14 hours was selected as optimal condition for this study and used throughout the rest of experimental program.

4.2.2 The Optimum Aluminium Content, Appropriate Water-to-Total Solid Ratio, and Binder-to- Aggregate Proportion

As proposed in preliminary testing program, twenty seven trial mixes were carried out to obtain the proper amount of aluminium powder, appropriate water-to-total solid ratio, binder-to-aggregate ratio base on physical and mechanical properties, compressive strength and density, of 1 day age of lightweight concrete subjected to variety of mix proportions. The testing results namely, compressive strength and density of different mix proportions were introduced in Table 4.5, Table 4.6, and Table 4.7. Whereas, Figure 4.7 and Figure 4.8 shown the comparison of compressive strength and density for all binder-to-aggregate ratios.

Table 4.5 Testing Results of Different Mixes at the Binder-to-Aggregate Proportion of 50:50

Mixes No.	Al powder content (%)	Water-to-TS ratio	Density (g/cm^3)	1-day compressive strength (ksc)
1	0.20	0.26	1.3237	142.30
2	0.20	0.29	1.2840	103.25
3	0.20	0.32	1.2326	77.68
4	0.25	0.26	1.2773	121.75
5	0.25	0.29	1.2263	79.40
6	0.25	0.32	1.1956	59.65
7	0.30	0.26	1.2198	102.65
8	0.30	0.29	1.1950	66.52
9	0.30	0.32	1.1476	50.25

Table 4.6 Testing Results of Different Mixes at the Binder-to-Aggregate Proportion of 55:45

Mixes No.	Al powder content (%)	Water-to-TS ratio	Density (g/cm^3)	1-day compressive strength (ksc)
1	0.20	0.26	1.1532	112.20
2	0.20	0.29	1.1072	88.52
3	0.20	0.32	1.0778	66.92
4	0.25	0.26	1.1047	104.58
5	0.25	0.29	1.0304	72.08
6	0.25	0.32	0.9491	41.50
7	0.30	0.26	1.0512	97.07
8	0.30	0.29	1.0314	82.62
9	0.30	0.32	1.0182	59.84

Table 4.7 Testing Results of Different Mixes at the Binder-to-Aggregate Proportion of 60:40

Mixes No.	Al powder content (%)	Water-to-TS ratio	Density (g/cm^3)	1-day compressive strength (ksc)
1	0.20	0.26	1.0551	95.52
2	0.20	0.29	1.0341	59.22
3	0.20	0.32	0.9948	50.33
4	0.25	0.26	1.0223	81.19
5	0.25	0.29	0.9831	52.04
6	0.25	0.32	0.9632	43.31
7	0.30	0.26	0.9745	59.29
8	0.30	0.29	0.9539	36.76
9	0.30	0.32	0.9464	26.28

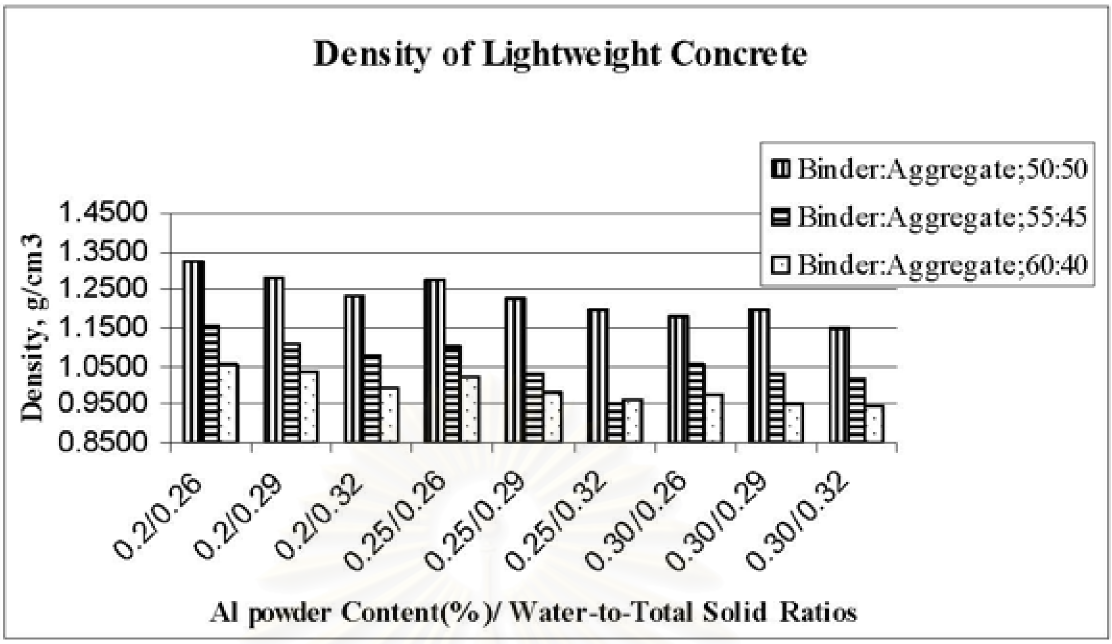


Figure 4.7 Comparison of Density of Lightweight Concrete Subjected to Varies Mix Proportions

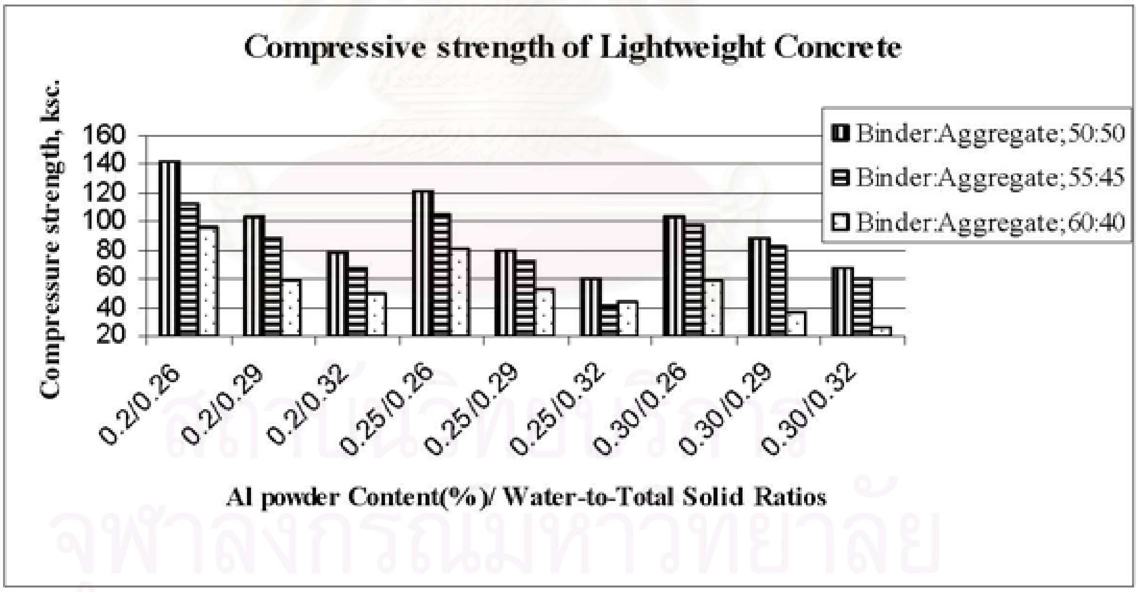


Figure 4.8 Comparison of Compressive Strength of Lightweight Concrete Subjected to Varies Mix Proportions

From the results, it can be observed that, with same amount of aluminum powder content and binder-to-aggregate ratio. The value of compressive strength of 1-day age lightweight mortar was related by water-to-total solid (W/TS) ratio, the lower ratio led to higher strength of lightweight concrete, which is consistent with Stamen and Bluefield (2002), who explained that the strength of concrete will decrease as matrix porosity increase, and that matrix porosity increase as the water-to-cementatious materials (c/cm) increase above optimum values. From this reason, at 0.26 of W/TS ratio or 0.472 water-to-binders ratio had resulted in highest strength. Beside, W/TS ratio also effected to the density of lightweight concrete that due to W/TS ratio response with matrix porosity as above mentioned. In addition, H_2O reacted with CaO produced hydrate lime ($Ca(OH)_2$ or CH), which CH plays important role for bubbles generation by aluminum powder.

The effect of aluminum powder can be used to note that the higher amount of aluminum powder used in the mix provided the lower density of the lightweight specimen. It can be explained by the fact that aluminum powder was reacted with CH then produced hydrogen gas to perform burbles in the matrix. From the results in Figure 4.7, it can be seen that the mix contained 0.3% of aluminum powder by weight of total solid resulted in minimum value of the density of lightweight concrete for all binder-to-aggregate ratios. This finding is in line with results from the previous studies of Ungsongkun (2005) and Phuythamajitt (2006). For the compressive strength, it noticed that the strength of lightweight specimen decreased with the increased of aluminum powder content, that because high aluminum content resulted in low density, and that low density reflected to low strength of lightweight mortar which is correspond with Gunawan (2006), who noted that the strength of lightweight concrete is a function of its density. In other words, the compressive strength was increased as the density of concrete increased.

From the effect of binder-to-aggregate ratio, with the same aluminum powder content and W/TS ratio, it can be mentioned that the binder-to-aggregate ratio responded with the density of lightweight mortar, it's density decreased with the increased of binder materials content since hydrogen gas liberation is governed by alkalis from binder materials, which is consistent with Neville (2002), who reported that the range of dry density of aerated concrete without aggregation was 200-300 kg/m^3. Whereas, the range of aerated concrete density with aggregation around 800-2080 kg /m^3, which may different from case by case. For the compressive the strength, it varied in the proportion to density of lightweight concrete. In sprite of the fact that the strength of aerated lightweight concrete depends on the amount of total void volume that is the sum of matrix porosity and induced void, but for this study, the compressive strength was only influenced by the volume of introduced void, which resulted from chemical reaction of aluminum powder. There was not compromised with W/TS ratio. Hence, it did not effected to the volume of matrix porosity.

Therefore, base on the results of the compressive strength and density of lightweight concrete in the series of twenty seven trial mixes, it recommended that the mix which contained 0.3% of aluminum powder by total solid weight, 0.26 W/TS ratio, and 55:45 of binder-to-aggregate ratio gave the highest strength and the lowest density as compared with other mixes in the line of series. From this rational, it was selected as the optimal mix proportion to make aerated lightweight concrete and was used in main testing program.

4.3 Test results of Main Testing Program

In this experiment, the optimal percentage of fly ash replacing main ingredient, Portland cement, was selected depending on their physical and mechanical properties of lightweight concrete namely, compressive strength, desired water adsorption, and density, which was cited in Table 4.8.

Table 4.8 The Results of Main Testing Program

Mix No.	Density (kg/m^3)	Compressive strength (ksc)	Water absorption (%)
Control	1,099	86	38.30
5%RH	1,119	77	32.62
10%RH	1,055	77	39.40
15%RH	1,164	80	34.56
20%RH	1,145	84	36.98
30%RH	1,080	100	37.56
40%RH	971	55	43.54
5%B3	1,177	83	38.09
10%B3	1,164	92	42.46
15%B3	1,131	95	45.82
20%B3	1,094	89	47.13
30%B3	1,066	96	45.67
40%B3	1,038	62	50.72
5%B4	1,160	86	39.29
10%B4	1,139	92	39.42
15%B4	1,114	90	41.27
20%B4	1,096	92	43.86
30%B4	1,071	99	47.07
40%B4	1,032	66	52.35

RH referred to rice husk

B_3 referred to biomass feed recipe # 3

B_4 referred to biomass feed recipe # 4

4.3.1 Density

The densities of lightweight mortar for all mixes were shown in Table 4.8 and Figure 4.9 presented graphically the comparison of aerated concrete for different percentage of fly ash replacement of primary raw material.

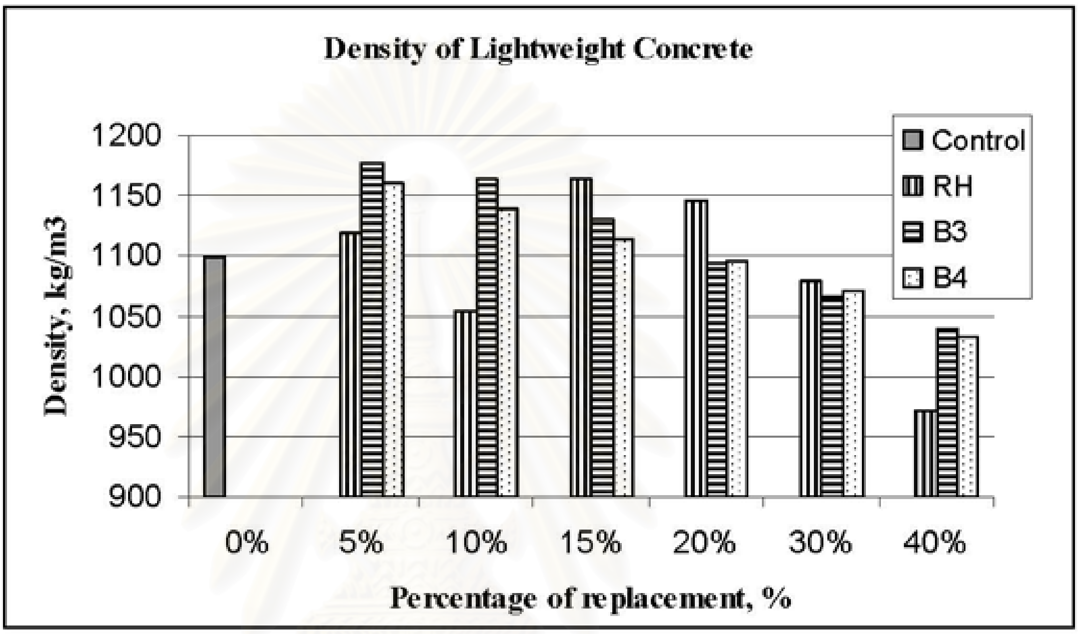


Figure 4.9 Comparison of Density of Lightweight Concrete for Different Percentage of Fly Ash Replacing Cement

It can be noticed from the tabulation of all mixes in Table 4.8 that, the density of lightweight concrete was maximum for the mix contained 15% of RH fly ash, 5% of B_3 fly ash, and 5% of B_4 fly ash, which was 1,119 kg/m^3 1,177 kg/m^3 and 1,160 kg /m^3, respectively. The minimum density was the mix contained 40% of RH fly ash, 40% of B_3 fly ash, and 40% B_4 fly ash, which was 971 kg/m^3, 1,038 kg/m^3, and 1,032 kg/m^3, respectively. From the comparison of density of lightweight concrete was stated in Figure 4.9. It can be seen that the density decreased as the amount of fly ash increased, these results were the same dramatically pattern to all three biomass fly ash.

From the observation in this experiment, it can be commented that the mixing sample contained 5% RH, 5%B_3, 15% B_3, 5B_3, 10%B_4, and 15%B_4 had higher densities than that of the control mixture. As the matter of fact, the density of aerated concrete is affected by the formation of gas by chemical reaction within the mass during plastic stage after cadting, the mix proportion and raw materials being used in the ingredient also influence on the formation of cellular structure. At this point, it be clarified that the hydrating reaction, which produce the product of lime or CH and reacts with aluminum powder to form air bubbles, as quoted in 4.2.2. CH and bubbles formation were reduced with the increased amount of fly ash replacing cement. Thus, the decreased formation of cellular structure in the matrix increased the lightweight mortar density

The remaining densities of aerated lightweight concrete was decreased with the increased of fly ash as cement replacement, this result can be illustrated that the density is a function of bulk specific gravity of materials (Ungsongkhun,2005). Since the bulk specific gravity of cement is the highest as compared with all three biomass fly ash as cited in Table 4.2. Thereby, the replacement content by biomass fly ash decreased the density of lightweight concrete.

4.3.2. Compressive strength

The testing results of the compressive strength of 1-day age lightweight concrete were shown in Table 4.8. And graphically represent in Figure 4.10.

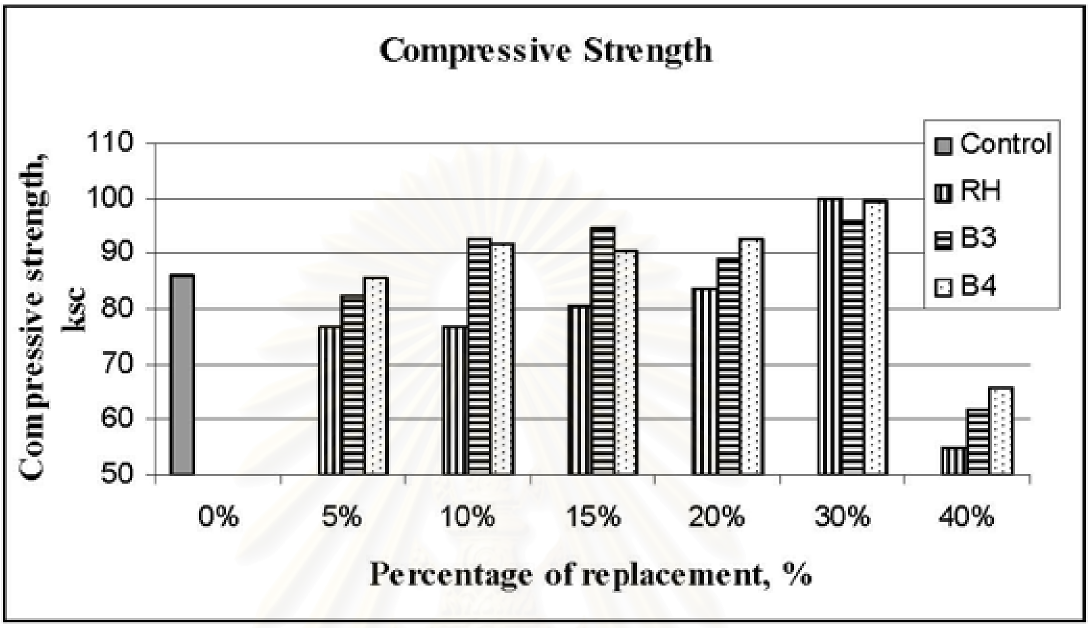


Figure 4.10 Comparison of Compressive Strength of Lightweight Mortar Containing Different Percentage of Biomass Fly Ash

From the results in Table 4.8, it shown that the mix containing 5%RH, 10%RH, 40%RH, 40%B_3, and 40%B_4 provided lower strength than that of the control mix while 30%RH, 10%B_3, 15%B_3 20%B_3, 30%B_3, 10%B_4, 15%B_4, 20%B_4, and 30%B_4 gave the higher strengths. On the other hand, the test samples of 40%RH, 40%B_3, and 40%B_4 showed the lowest strength. But it was interested to note that the strengths of aerated concrete were a fluctuation in the same range while the density decreased as the percent of replacement increased.

In general, the strength is related with the density of concrete, that is, the strength of concrete can be expressed as a function of total voids volume in concrete matrix. On the other words, the strength is influenced by w/cm ratio which results in the matrix porosity, and also effected by volume of induced void (from chemical reaction of aluminum powder). In this part of the study, the amount of water content was fixed at 0.26 of W/TS ratio throughout experimental program. Thus, there was not compromised by amount of matrix porosity. On the other hand, as compared the value of bulk specific surface area of three biomass fly ash and Portland cement which was shown in Table 4.1, it indicated that all three biomass fly ash were higher than Portland cement and that reflected to their chemical reactivity. Beside, the high value of specific surface area also results in high water demand (Mindess, Young, and Darwin, 2003). So that, the amount of water content in the mix should not higher than the optimal amount. For the induced voids, the volume of induced voids is governed by chemical reaction between CH and aluminum powder, the amount of induced voids should be decreased with the amount of fly ash replacing cement increased as already discussed in previous sections, from these reasons, it can be used to explain that why the compressive strength of lightweight concrete were not decreased though the density decreased.

For the mix of 40%RH, 40% B_4, and 40%B_3, that was the lowest strength as compared with other. This might be due to the amount of calcium oxide (CaO) had not enough to complete the pozzolanic reaction with siliceous materials, which is consistent with Swamy (1993), who suggested that under high pressure steam and high temperature curing, it's speed up the pozzolanic reaction between Portland cement and often added lime, with fine siliceous sand or fly ash or the mixture of the two materials. The calcium silicate Hydrate (C-S-H) formed initially reacts with added silica in the mix so that the end product has a Ca / (Al + Si) ratio of 0.8. In this study, the mix of 30% replacement was a Ca / (Al + Si) ratio of approximately 0.8 while the test sample of 40% replacement a Ca /(Al + Si) ratio was about 0.6, it can be used to note that there were some unreacted silica remains. Then, it was compromised on the compressive strength of aerated concrete.

4.3.3. Desired Water Absorption

The desired water absorption for different mixes was tabulated in Table 4.8 and was graphically show in Figure 4.11.

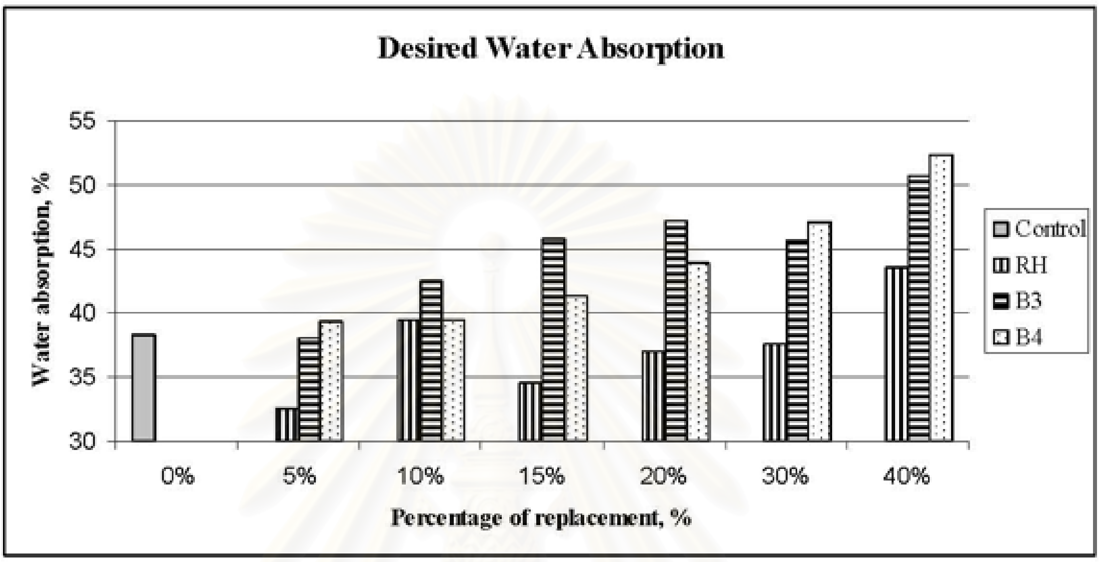


Figure 4.11 Comparison of Desired Water Absorption of Lightweight Mortar Containing Various Amount of Fly Ash Replacing Cement Used

From the results in Table 4.8, the maximum water absorption was obtained for the mix of 40%RH, 40%B_3, and40%B_4, which was 43.54%, 50.72%, and 52.35%, respectively. Whereas, the minimum water absorption was for the mix containing 5%RH, 5%B_3, and 5%B_4, 32.62%, 38.09%, and 39.29%, respectively.

From the Figure 4.11, it can be seen the higher percentage of fly ash replacing cement provided the higher amount of water absorption, for this finding also consistence with Gunawan (2006). This is due to the intrinsic properties of fly ash that low specific gravity and high porosity. And due to the density of lightweight mortar was reduced as an increased of fly ash replacement as already quoted in previous section. Hence, it can be also stated that the desired water absorption of aerated concrete is a function of density.

4.3.4 Cost Analysis

Table 4.9 was illustrated the amount of raw materials used calculation for fresh concrete of control mix, other mix computations were tabulated Appendix. The cost comparison of all mixes was shown in Table 4.10 and was graphically presented in Fig 4.12.

Table 4.9 Cost Computation for Control Mix

Materials	**Amount used in the mix, W (kg/m^3)**	**Bulk Specific Gravity, G**	**Unit weight of material, γ (kg/m^3)**	**Volume of material, V $V=W/\gamma$ (m^3)**
Water	182.00	1.00	1000	0.1820
Portland cement	346.50	3.15	3150	0.1100
Lime	38.50	3.05	3050	0.0126
River sand	315.00	2.75	2750	0.1145
Al powder	2.10	1.50	1500	0.0014
Air	-	-	-	V_a
Total	884.10	11.45	11450	$0.4206 + V_a$

V_a referred to volume of air

The entity volume of concrete = Total weight of materials in the mix / Unit weight or Density of concrete m^3

= $884.10 / 1099\ m^3$

= $0.8045\ m^3$

The volume of air = Volume of concrete – Volume of all materials m^3

= $0.8045 - 0.4206\ m^3$

= $0.3839\ m^3$ or 38.39% by volume of air

Then, there would be calculated the amount of each material for manufacture a cubic meter of fresh aerated lightweight concrete as following:

Water used = 182.00 / 0.8045 = 227.50 kg/m^3

Cement used = 346.50 / 0.8045 = 433.13 kg/m^3

Lime used = 38.5 / 0.8045 = 48.13 kg/m^3

Sand used = 315 / 0.8045 = 393.75 kg/m^3

Al powder used = 2.10 / 0.8045 = 2.63 kg/m^3

Table 4.10 Cost Comparison of Lightweight Mortar for Different Percentage of Fly Ash Replacement

	Cost (Baht/m^3)	**Mix No.**	**Cost (Baht/m^3)**
Control mix	3,779	30%B$_3$	3,463
10%RH	3,577	40%B$_3$	3,390
20%RH	3,729	10%B$_4$	3,772
30%RH	3,492	20%B$_4$	3,957
40%RH	3,184	30%B$_4$	3,463
10%B$_3$	3,844	40%B$_4$	3,309
20%B$_3$	3,597	-	-

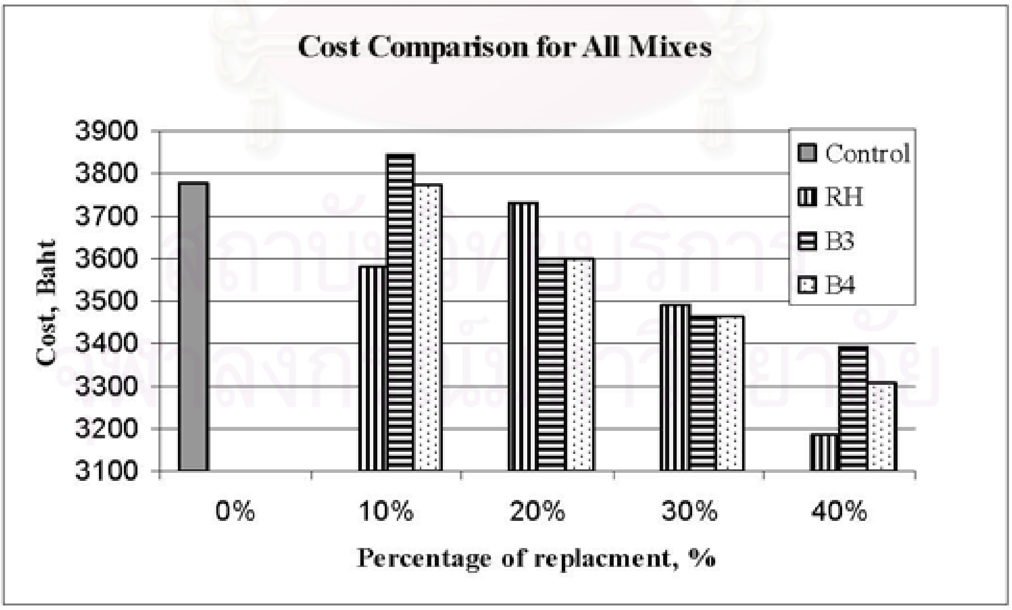


Figure 4.12 Cost Comparison of Aerated Lightweight Concrete Subjected Various Percentage of Replacement.

From the data, it can be seen that the highest cost was 40%B_4, which was 3,957 Baht/m^3 while the lowest cost was the mix for 40% RH which was 3,184 Baht/m^3. For the remaining mixtures were varies from 3,309-3,844 Baht/m^3. From the cost comparison in Figure 4.12, it can be used to note that, aerated lightweight concrete's initial cost was reduced as the percentage of fly ash replacement increased.

From the information in this study, only the initial production cost from laboratory scale, it could not enough to use as the representative of real production cost in plant manufacturer scale. The higher level of experimental scale has obligated as such pilot scale at least. Moreover, the transportation cost is always important for economical mean both the transportation cost of raw materials and/or finished products to stakeholder that have to be taken into consideration In this study, it can be concluded that the initial production cost of autoclaved aerated lightweight concrete was decreased as the percentage of fly ash replacement increased. But it could not used to mention for real production cost.

4.3.5 Optimum Mix Proportions

In order to identify which mix should be the optimum mix proportion in this study, it can be considered in many aspects depending on the results obtain from the experiment, which are density, strength, and production cost as shown in Table 4.8 and 4.9, the purpose for using the aerated lightweight concrete and the use of waste materials available in Thailand for environmental sustainability. The reason for selecting the optimum mix proportion as the following:

1. Density: it can be noted that the density of aerated lightweight mortar from all mixes, if the density is the criterion, the mix of 40% RH, 40% B_3, and 40% B_4 which shown the lowest density, should be the suitable mix proportion
2. Compressive strength: from the data obtained the mix of 30% RH, 30% B_3, and 30% B_4 which shown the highest strength as compared with other mix proportion with the same kind of biomass fly ash. There can be introduced to use in the construction applications. Therefore, this mix proportion can be considered to be the optimum mix proportion which can be conducted in practice.
3. Cost: in practice, cost is the main subject for making a decision. Base on the production cost as the criterion, for this study the mix of 40% RH, 40% B_3, and 40% B_4 was recommended.
4. Base on the density and compressive strength: as considered the results both density and compressive strength are criterion, the mix of 30% RH, 30% B_3, and 30% B_4 was selected.
5. Base on the properties of control mix: to find the amount of fly ash replacing main material, Portland cement, is the one of main objective for this study. If the value of density, compressive strength, and water absorption are criterion for this consideration, the mix 30% RH, 20% B_3, and 20% $B_4$was the most proportion mix that close to the control mix properties as compared with other.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Base on the results, which obtained from this study the following conclusion can be drawn:

5.1.1 Physical and Chemical Properties Investigation

From the observation of physical and chemical properties of fly ash, it can be used to note that all three biomass fly ash fit F-class pozzolan and could be as natural pozzolanic material in constructing application.

5.1.2 Preliminary Testing Program

The objectives of preliminary testing program were to find the optimal curing time, suitable amount of aluminium powder content, appropriate water-to-total solid ratio, and optimal binder-to-aggregate ratio to make aerated lightweight concrete. The conclusion as follow:

1. Base on the results of 1 day strength, it can be used to state that the curing period of 14 hours was the optimal duration for this study.
2. Base on the value of parameters namely, 1-day compressive strength and density under the different mix proportion of lightweight mortar, it was recommended that 0.30% of aluminium powder content, 0.26 of water-to-total solid ratio (0.472 of water-to-binder ratio), and 55/45 of binder-to-aggregate ratio were the optimal values and be used to make lightweight mortar in this study.

5.1.3 Main Testing Program

From the results in this experiment, it can be used to conclude as follow:

1. The higher amount of biomass fly ash used, it resulted in lower density of aerated lightweight concrete.

2. The cost of lightweight concrete decreased with the increased content of fly ash used.

3. Base on the results of parameters namely, compressive strength, density, and desired water absorption, it can be used to advice that the optimal mix proportion be 30%RH, 20%B_3, and 20%B_3 which used the highest amount of biomass fly ash replacement and did not compromise the aerated lightweight mortar properties as compared with control mix.

4. Base on the results of the compressive strength as criterion, the mix of 30%RH, 30%B_3, and 30%B_3 was recommended to use in the practice for construction applications

5. In order to maximize use of waste materials in Thailand as mean for environmental management, the mix containing 40% of biomass fly ash should be used in lower strength applications.

Finally, it can be concluded that all three biomass fly ash from biomass power plant in chachoengsao province of Thailand can be satisfactorily used as cement replacement for making aerated lightweight concrete. In addition, utilization of these waste products will also reduce pollution and disposal problems caused by them.

5.2 Recommendations

The recommendation for future studies as the following:

1. Investigation on the long-term durability of lightweight concrete containing biomass fly ash as main ingredient.
2. Investigation on the effect of curing on the compressive strength of lightweight mortar at higher pressure.
3. Improve the color of lightweight mortar containing biomass fly ash as main ingredient.
4. Investigation on the physical and mechanical properties of lightweight using bottom ash as aggregate material.

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APPENDICES

APPENDIX A

Preliminary Testing Program

Table A-1 Compressive Strength of Lightweight Mortar Subjected to Various Curing Periods

Curing periods (hrs.)	Width (mm)	Length (mm)	Area (cm^2)	Load (kN)	Stress (ksc)	Average Stress (ksc)
10	51.20	51.34	26.29	16.30	63.24	51.27
	50.57	51.62	26.10	11.50	44.88	
	50.82	51.56	26.20	11.70	45.70	
12	51.33	51.42	26.39	20.60	79.56	84.32
	50.33	51.27	25.80	21.70	85.68	
	50.99	51.59	26.31	22.60	87.72	
14	51.18	50.88	26.04	25.00	97.92	104.72
	51.34	50.57	25.96	27.00	106.08	
	51.11	50.54	25.83	27.90	110.16	
16	51.45	50.94	26.21	29.40	114.24	108.80
	51.36	50.68	26.03	28.10	110.16	
	51.28	50.98	26.14	26.10	102.00	

Table A-2 Density of Lightweight Concrete Containing Different Mixes at the Binder-to-Aggregate Proportion of 50:50

Mix No.	Al content:W/TS ratio	Width (mm)	Length (mm)	Height (mm)	Weight (g)	Density (kg/m^3)	Average Density (kg/m^3)
1	0.20:0.26	50.92	51.16	51.44	181.19	1,352.1	1,315
		50.83	50.57	51.33	173.17	1,312.5	
		50.25	51.31	50.87	175.44	1,337.6	
2	0.20:0.29	50.71	51.33	51.03	175.44	1,320.8	1,309
		50.48	51.32	51.34	175.42	1,318.9	
		50.63	51.21	51.44	174.17	1,305.9	
3	0.20:0.32	50.52	51.34	51.59	174.65	1,305.2	1,277
		50.86	51.39	51.60	176.77	1,310.7	
		50.69	50.91	51.53	174.67	1,313.5	
4	0.25:0.26	50.36	50.21	51.29	165.47	1,275.9	1,268
		50.84	50.37	51.55	169.45	1,283.6	
		50.62	50.81	51.04	167.03	1,272.4	
5	0.25:0.29	51.06	50.94	51.02	168.04	1,266.3	1,263
		51.20	51.44	51.08	168.80	1,254.7	
		51.07	51.35	51.03	169.77	1,268.6	
6	0.25:0.32	50.78	50.82	51.13	166.00	1,258.1	1,263
		50.64	51.04	51.21	167.95	1,268.9	
		51.33	51.75	50.79	170.34	1,262.6	
7	0.30:0.26	50.78	50.87	51.49	156.94	1,179.9	1,178
		50.45	50.88	51.46	155.94	1,180.5	
		50.85	51.32	51.04	156.52	1,175.1	
8	0.30:0.29	51.42	50.62	51.23	161.31	1,209.7	1,213
		51.48	51.19	51.27	164.19	1,215.2	
		50.85	50.90	51.71	162.78	1,216.2	
9	0.30:032	50.82	50.84	51.67	160.96	1,205.7	1,204
		50.95	50.98	51.19	159.85	1,202.2	
		51.39	51.45	51.03	162.46	1,204.1	

Table A-3 Density of Lightweight Concrete Containing Different Mixes at the Binder-to-Aggregate Proportion of 55:45

Mix No.	Al content:W/TS ratio	Width (mm)	Length (mm)	Height (mm)	Weight (g)	Density (kg/m^3)	Average Density (kg/m^3)
1	0.20:0.26	51.26	51.24	51.67	156.91	1,156.2	1,153
		50.95	50.68	51.19	153.25	1,159.4	
		50.87	51.19	51.03	152.02	1,144.0	
2	0.20:0.29	51.31	51.02	51.18	147.74	1,102.7	1,107
		50.86	51.09	50.9	146.16	1,105.1	
		51.24	51.29	50.92	149.05	1,113.8	
3	0.20:0.32	50.82	51.38	50.82	142.32	1,072.5	1,077
		51.07	50.79	51.28	143.43	1,078.3	
		51.06	51.08	50.67	143.77	1,087.9	
4	0.25:0.26	50.92	50.74	50.88	145.09	1,103.7	1,105
		50.66	51.09	51.03	145.65	1,102.8	
		50.43	50.85	51.14	145.53	1,109.7	
5	0.25:0.29	50.58	51.27	51.45	137.24	1,028.6	1,030
		50.82	51.01	51.36	137.86	1,035.4	
		50.97	51.42	51.28	138.05	1,027.2	
6	0.25:0.32	50.78	51.12	50.95	126.10	953.4	949
		50.69	51.67	51.22	126.53	943.2	
		50.48	51.62	51.10	126.59	950.7	
7	0.30:0.26	51.29	51.28	50.82	141.50	1,058.6	1,051
		51.40	51.57	50.72	143.81	1,069.7	
		51.25	51.19	50.75	136.82	1,027.6	
8	0.30:0.29	51.46	51.20	51.25	138.92	1,028.8	1,031
		51.28	50.57	50.96	136.41	1,032.2	
		51.45	50.82	50.88	137.45	1,033.2	
9	0.30:032	51.51	51.33	51.10	137.84	1,020.2	1,036
		51.56	50.33	51.71	136.80	1,019.5	
		51.23	50.99	50.87	134.86	1,014.9	

Table A-4 Density of Lightweight Concrete Containing Different, Mixes at the Binder-to-Aggregate Proportion of 60:40

Mix No.	Al content:W/TS ratio	Width (mm)	Length (mm)	Height (mm)	Weight (g)	Density (kg/m^3)	Average Density (kg/m^3)
1	0.20:0.26	51.24	51.40	50.74	133.94	1,002.3	1,055
		51.01	51.60	51.26	133.84	992.0	
		51.02	51.24	51.04	132.11	990.1	
2	0.20:0.29	51.08	51.38	50.86	136.42	1,022.0	1,034
		51.04	51.24	50.56	135.53	1,025.0	
		51.13	51.23	50.62	135.23	1,019.9	
3	0.20:0.32	51.05	51.31	50.36	128.98	977.8	995
		50.98	51.48	50.54	130.65	985.0	
		51.22	51.08	50.35	129.95	986.5	
4	0.25:0.26	51.41	50.97	50.35	127.38	965.5	1,022
		51.41	51.43	50.28	128.10	963.6	
		50.75	51.32	50.36	125.98	960.5	
5	0.25:0.29	51.05	51.34	50.88	129.62	972.0	983
		50.91	51.62	50.57	128.71	968.5	
		51.24	51.56	50.54	131.25	983.0	
6	0.25:0.32	51.21	51.42	50.94	127.50	950.5	963
		51.41	51.27	50.68	127.86	957.2	
		51.34	51.59	50.98	128.82	954.0	
7	0.30:0.26	51.46	51.49	50.68	127.21	947.3	975
		51.16	51.77	51.21	128.92	950.5	
		50.57	51.53	51.10	125.36	941.4	
8	0.30:0.29	50.96	51.62	50.69	127.86	958.9	954
		51.02	51.28	50.48	124.87	945.5	
		51.36	51.57	51.29	130.05	957.3	
9	0.30:032	51.14	51.28	50.82	125.57	942.2	946
		51.32	51.57	50.95	127.93	948.7	
		51.57	51.19	51.39	128.65	948.3	

Table A-5 Compressive Strength of Lightweight Concrete Containing Different Mixes at the Binder-to-Aggregate Proportion of 50:50

Mix No.	**Al content:W/TS ratio**	**Width (mm)**	**Length (mm)**	**Area (cm^2)**	**Load (kN)**	**Stress (ksc)**	**Average Stress (ksc)**
1	0.20:0.26	50.48	51.33	25.91	37.80	148.63	142.33
		51.29	50.81	26.06	36.00	140.82	
		51.40	50.41	25.91	34.90	137.54	
2	0.20:0.29	51.25	49.95	25.60	26.50	105.46	103.25
		51.46	50.93	26.21	28.00	108.77	
		51.28	50.53	25.91	24.30	95.52	
3	0.20:0.32	51.45	51.53	26.51	19.60	75.48	77.68
		51.51	50.67	26.10	20.30	79.50	
		51.56	50.83	26.21	20.10	78.06	
4	0.25:0.26	51.23	50.77	26.01	30.30	118.95	121.75
		51.60	49.92	25.76	30.90	122.36	
		51.58	50.23	25.91	31.50	123.94	
5	0.25:0.29	51.14	50.57	25.86	20.40	80.50	79.39
		51.32	51.07	26.21	20.00	77.62	
		51.57	49.45	25.50	19.00	76.04	
6	0.25:0.32	50.97	49.64	25.30	15.00	60.52	59.65
		51.43	50.09	25.76	15.70	62.33	
		51.32	49.88	25.60	14.10	56.09	
7	0.30:0.26	51.34	49.18	25.25	26.10	105.25	103.25
		51.62	49.98	25.80	25.20	99.68	
		51.56	49.65	25.60	26.30	104.82	
8	0.30:0.29	51.42	48.74	25.06	37.80	89.57	88.54
		51.27	49.35	25.30	36.00	85.36	
		51.59	51.62	26.63	34.90	87.69	
9	0.30:032	51.49	50.32	25.91	26.50	70.23	67.21
		51.77	50.22	26.00	28.00	65.55	
		51.53	50.57	26.06	24.30	65.85	

Table A-6 Compressive Strength of Lightweight Concrete Containing Different Mixes at the Binder-to-Aggregate Proportion of 55:45

Mix No.	Al content:W/TS ratio	Width (mm)	Length (mm)	Area (cm^2)	Load (kN)	Stress (ksc)	Average Stress (ksc)
1	0.20:0.26	51.28	51.01	26.16	29.60	115.26	112.20
		51.57	49.64	25.60	27.70	110.24	
		51.28	48.85	25.05	27.30	111.1	
2	0.20:0.29	51.57	50.73	26.16	22.50	87.58	88.52
		51.19	50.32	25.76	22.90	90.63	
		51.33	51.26	26.31	22.50	87.35	
3	0.20:0.32	51.32	51.29	26.32	16.90	65.58	66.92
		51.21	49.58	25.39	16.50	66.31	
		51.34	50.95	26.16	17.70	68.87	
4	0.25:0.26	51.39	50.61	26.01	25.70	100.58	104.58
		50.91	51.09	26.01	26.90	105.63	
		50.21	52.10	26.16	27.60	107.53	
5	0.25:0.29	50.37	50.72	25.55	18.70	74.52	72.08
		50.81	51.17	26.00	18.20	71.23	
		50.94	51.57	26.27	18.20	70.49	
6	0.25:0.32	50.95	51.25	26.11	10.30	40.26	41.50
		51.22	51.29	26.27	11.40	44.23	
		51.10	51.00	26.06	10.20	40.01	
7	0.30:0.26	50.82	49.33	25.07	24.50	99.58	97.07
		50.72	51.26	26.00	24.4	95.55	
		50.75	51.65	26.21	24.7	96.06	
8	0.30:0.29	51.25	49.85	25.55	20.9	83.56	82.62
		50.96	50.04	25.50	20.6	82.22	
		50.88	50.22	25.55	20.6	82.08	
9	0.30:032	51.1	50.61	25.86	15.4	60.56	59.84
		50.99	51.21	26.11	14.2	55.27	
		50.27	52.66	26.47	16.5	63.69	

Table A-7 Compressive Strength of Lightweight Concrete Containing Different, Mixes at the Binder-to-Aggregate Proportion of 60:40

Mix No.	Al content:W/TS ratio	Width (mm)	Length (mm)	Area (cm^2)	Load (kN)	Stress (ksc)	Average Stress (ksc)
1	0.20:0.26	50.66	51.74	26.21	24.50	95.26	95.52
		50.62	50.99	25.81	24.70	97.45	
		50.36	50.24	25.30	23.30	93.85	
2	0.20:0.29	50.54	49.96	25.25	15.00	60.58	59.22
		50.35	53.51	26.94	15.20	57.45	
		50.35	52.06	26.21	15.30	59.63	
3	0.20:0.32	50.28	50.52	25.40	12.30	49.58	50.33
		50.36	51.35	25.86	13.20	52.21	
		50.88	51.12	26.01	12.50	49.20	
4	0.25:0.26	50.57	51.33	25.96	20.50	80.56	81.19
		50.54	51.76	26.16	21.40	83.49	
		50.94	51.26	26.11	20.40	79.52	
5	0.25:0.29	50.68	52.03	26.37	14.10	54.44	52.04
		50.98	50.82	25.91	13.30	52.26	
		50.68	51.52	26.11	12.60	49.30	
6	0.25:0.32	51.21	49.99	25.60	11.70	46.56	43.31
		51.22	49.88	25.55	10.60	42.35	
		51.41	51.49	26.47	10.60	41.02	
7	0.30:0.26	51.41	51.68	26.57	15.70	60.27	59.29
		50.75	52.35	26.57	15.30	58.77	
		51.05	51.75	26.42	15.20	58.83	
8	0.30:0.29	50.91	50.09	25.50	9.10	36.52	36.76
		51.24	50.57	25.91	9.50	37.55	
		51.21	50.89	26.06	9.30	36.21	
9	0.30:032	51.41	50.22	25.82	6.50	25.59	26.28
		51.34	50.86	26.11	7.00	27.44	
		50.64	50.75	25.70	6.50	25.84	

APPENDIX B

Main Testing Program

Table B-1 Density of Lightweight Concrete for Different Percentage of Rice Husk Fly Ash Replacing Cement

Mix Destination	Width (mm)	Length (mm)	Height (mm)	Weight (g)	Density (kg/m^3)	Average Density (kg/m^3)
Control mix	51.14	50.36	50.99	144.65	1,101.5	1,099
	51.45	50.84	51.18	145.56	1,087.3	
	51.36	50.62	51.34	147.92	1,108.3	
5%RH	51.26	51.28	50.26	145.37	1,100.3	1,119
	50.95	51.57	50.80	148.46	1,112.3	
	50.87	51.19	51.24	152.55	1,143.3	
10%RH	51.20	51.40	50.46	138.93	1,046.2	1,055
	50.57	51.60	51.30	140.70	1,051.1	
	50.82	51.24	50.90	141.46	1,067.2	
15%RH	50.82	51.06	51.66	157.72	1,176.6	1,164
	51.07	51.37	50.87	154.22	1,155.6	
	51.06	51.21	50.63	153.61	1,160.4	
20%RH	50.92	51.33	51.27	154.00	1,149.2	1,145
	50.66	50.33	51.88	151.70	1,146.8	
	50.43	50.99	50.60	148.25	1,139.4	
30%RH	51.18	51.12	51.25	143.19	1,068.0	1,080
	51.34	51.67	50.26	145.69	1,092.7	
	51.11	51.62	50.32	143.21	1,078.7	
40%RH	51.27	51.31	51.55	129.63	955.9	971
	51.01	50.86	50.63	127.93	974.0	
	51.42	51.24	50.44	130.68	983.3	

RH referred to rice hush fly ash

Table B-2 Density of Lightweight Concrete for Different Percentage of Biomass feed recipe #3 Fly Ash Replacing Cement

Mix Destination	Width (mm)	Length (mm)	Height (mm)	Weight (g)	Density (kg/m^3)	Average Density (kg/m^3)
Control mix	51.14	50.36	50.99	144.65	1,101.5	1,099
	51.45	50.84	51.18	145.56	1,087.3	
	51.36	50.62	51.34	147.92	1,108.3	
5%B_3	51.23	50.78	51.49	158.07	1,180.1	1,177
	51.27	50.74	51.46	157.72	1,178.2	
	51.71	50.98	51.04	157.84	1,173.1	
10% B_3	51.18	50.87	50.82	155.02	1,171.7	1,164
	51.34	50.87	50.72	154.25	1,164.5	
	51.11	50.74	50.75	152.13	1,155.9	
15% B_3	51.62	50.74	51.25	152.77	1,138.1	1,131
	51.56	51.26	50.96	150.95	1,120.8	
	51.42	51.04	50.88	151.34	1,133.3	
20% B_3	50.57	50.86	51.10	143.36	1,090.8	1,094
	50.82	50.56	51.71	145.02	1,091.5	
	51.67	50.62	51.34	147.69	1,099.8	
30% B_3	51.13	50.36	51.20	139.13	1,055.4	1,065
	51.21	50.54	50.57	139.96	1,069.3	
	50.79	50.35	50.82	139.32	1,072.0	
40% B_3	50.88	50.35	51.33	137.01	1,041.9	1,038
	50.87	50.28	50.33	133.85	1,039.8	
	51.27	50.36	50.99	136.07	1,033.5	

B_3 referred to fly ash resulting from biomass feed recipe#3

Table B-3 Density of Lightweight Concrete for Different Percentage of Biomass feed recipe #4 Fly Ash Replacing Cement

Mix Destination	Width (mm)	Length (mm)	Height (mm)	Weight (g)	Density (kg/m^3)	Average Density (kg/m^3)
Control mix	51.14	50.36	50.99	144.65	1,101.5	1,099
	51.45	50.84	51.18	145.56	1,087.3	
	51.36	50.62	51.34	147.92	1,108.3	
5%B_4	50.78	50.88	51.18	152.33	1,152.0	1,160
	50.74	50.57	51.34	154.11	1,169.8	
	51.03	50.54	51.11	152.70	1,158.5	
10% B_4	51.19	50.94	51.06	152.01	1,141.7	1,139
	51.03	50.68	51.37	150.87	1,135.6	
	51.67	50.98	51.21	153.82	1,140.3	
15% B_4	51.06	50.95	51.4	149.56	1,118.5	1,114
	51.37	51.22	51.6	151.34	1,114.7	
	51.21	51.1	51.24	148.78	1,109.6	
20% B_4	51.33	51.31	51.38	149.14	1,102.1	1,095
	50.33	51.48	51.24	145.48	1,095.8	
	50.99	51.08	51.23	145.36	1,089.4	
30% B_4	51.4	50.97	51.31	144.47	1,074.7	1,071
	51.6	51.43	51.48	146.92	1,075.4	
	51.24	51.32	51.08	142.79	1,063.0	
40% B_4	51.38	51.45	50.97	140.65	1,043.8	1,031
	51.24	51.36	51.43	137.59	1,016.6	
	51.23	51.28	51.32	139.61	1,035.5	

B_4 referred to fly ash resulting from biomass feed recipe #4

Table B-4 Compressive strength of Lightweight Concrete for Different Percentage of Rice Husk Fly Ash Replacing Cement

Mix Destination	Width (mm)	Length (mm)	Area (cm^2)	Load (kN)	Stress (ksc)	Average Stress (ksc)
Control mix	50.96	51.28	26.13	23.10	90.23	86.42
	51.28	51.88	26.60	22.30	85.56	
	51.47	51.77	26.65	21.80	83.38	
5%RH	51.40	51.43	26.44	20.10	77.52	76.84
	51.60	51.64	26.65	19.70	75.48	
	51.19	51.64	26.43	20.10	77.52	
10%RH	51.04	51.05	26.06	18.80	73.44	76.84
	51.25	50.45	25.86	19.10	75.48	
	51.29	51.1	26.21	21.00	81.60	
15%RH	51.49	51.87	26.71	20.80	79.56	80.24
	51.42	50.48	25.96	19.20	75.48	
	50.68	51.10	25.90	21.80	85.68	
20%RH	51.36	50.46	25.92	20.70	81.60	83.64
	50.84	50.93	25.89	21.20	83.64	
	51.48	50.73	26.12	21.90	85.68	
30%RH	51.535	51.33	26.45	26.50	102.00	99.96
	51.36	50.93	26.16	25.60	99.96	
	50.66	50.59	25.63	24.60	97.92	
40%RH	51.37	50.78	26.09	13.60	53.04	54.67
	51.17	50.4	25.79	15.00	59.16	
	50.87	50.76	25.82	13.10	51.816	

Table B-5 Compressive strength of Lightweight Concrete for Different Percentage of Biomass Feed Recipe #3 Replacing Cement

Mix Destination	**Width (mm)**	**Length (mm)**	**Area (cm^2)**	**Load (kN)**	**Stress (ksc)**	**Average Stress (ksc)**
Control mix	50.96	51.28	26.13	23.10	90.23	86.42
	51.28	51.88	26.60	22.30	85.56	
	51.47	51.77	26.65	21.80	83.38	
5%B_3	50.41	50.97	25.69	19.50	77.52	82.55
	51.05	50.97	26.02	21.00	82.416	
	52.17	51.48	26.86	23.10	87.72	
10% B_3	51.09	50.71	25.91	23.80	93.84	92.48
	51.06	50.75	25.91	23.30	91.80	
	51.45	50.85	26.16	23.60	91.80	
15% B_3	51.4	51.14	26.29	24.20	93.84	94.52
	50.81	50.85	25.84	25.30	99.96	
	51.01	50.51	25.77	22.70	89.76	
20% B_3	51.05	51.33	26.20	22.00	85.68	89.08
	50.75	51.42	26.10	23.00	89.76	
	50.77	51.00	25.89	23.30	91.80	
30% B_3	50.34	50.75	25.55	23.50	93.84	95.44
	51.58	50.5	26.05	25.00	97.92	
	50.98	50.97	25.98	24.40	95.88	
40% B_3	50.34	51.61	25.98	16.20	63.59	61.88
	51.66	51.34	26.52	15.70	60.27	
	51.48	51.20	26.36	16.00	61.78	

Table B-6 Compressive strength of Lightweight Concrete for Different Percentage of Biomass Feed Recipe #4 Replacing Cement

Mix Destination	**Width (mm)**	**Length (mm)**	**Area (cm^2)**	**Load (kN)**	**Stress (ksc)**	**Average Stress (ksc)**
Control mix	50.96	51.28	26.13	23.10	90.23	86.42
	51.28	51.88	26.60	22.30	85.56	
	51.47	51.77	26.65	21.80	83.38	
5%B_4	51.15	50.77	25.97	22.90	89.76	85.68
	51.26	50.54	25.91	20.70	81.60	
	51.06	51.04	26.06	21.90	85.68	
10% B_4	51.31	51.80	26.58	23.40	89.76	91.80
	50.82	51.34	26.09	23.50	91.80	
	51.10	51.24	26.18	24.10	93.84	
15% B_4	51.28	51.29	26.30	24.20	93.84	90.44
	51.63	51.63	26.66	24.00	91.80	
	51.82	51.22	26.54	22.30	85.68	
20% B_4	51.26	51.40	26.35	24.20	93.84	92.48
	51.63	51.26	26.47	23.30	89.76	
	51.31	50.23	25.77	23.70	93.84	
30% B_4	51.34	51.13	26.25	25.20	97.92	99.28
	51.44	51.25	26.36	26.40	102.00	
	50.28	51.44	25.86	24.80	97.92	
40% B_4	50.97	51.16	26.08	16.20	63.24	65.96
	51.15	51.68	26.43	18.00	69.36	
	51.31	51.65	26.50	17.00	65.28	

Table B-7 Water Absorption of Lightweight Concrete for Different Percentage of Rice Husk Fly Ash Replacing Cement

Mix Destination	**Dry Weight (g)**	**Saturated Surface Weight (g)**	**Water Absorption (%)**	**Average Water Absorption (%)**
Control	142.32	196.11	31.12	38.30
	143.43	200.15	32.91	
	143.77	197.76	33.83	
5%RH	140.29	183.95	31.12	32.62
	141.81	188.48	32.91	
	145.77	195.09	33.83	
10%RH	133.39	177.23	32.87	39.40
	134.02	177.78	32.65	
	136.07	183.25	34.67	
15%RH	150.01	199.32	32.87	34.56
	147.34	200.22	35.89	
	147.94	199.61	34.92	
20%RH	146.52	200.83	37.06	36.98
	146.22	200.51	37.13	
	145.27	198.65	36.74	
30%RH	136.17	187.01	37.33	37.56
	139.32	191.12	37.18	
	137.54	190.05	38.17	
40%RH	121.88	175.30	43.84	43.54
	124.18	178.16	43.46	
	125.37	179.70	43.33	

Table B-8 Water Absorption of Lightweight Concrete for Different Percentage of Biomass Feed Recipe #3 Fly Ash Replacing Cement

Mix Destination	Dry Weight (g)	Saturated Surface Weight (g)	Water Absorption (%)	Average Water Absorption (%)
Control	142.32	196.11	31.12	38.30
	143.43	200.15	32.91	
	143.77	197.76	33.83	
5%B_3	150.46	205.60	36.64	38.09
	150.21	207.42	38.08	
	149.57	208.71	39.54	
10% B_3	149.39	211.69	41.71	42.46
	148.47	211.04	42.14	
	147.38	211.51	43.52	
15% B_3	145.11	209.61	44.46	45.82
	142.90	210.30	47.17	
	144.50	210.72	45.82	
20% B_3	139.07	199.64	43.55	47.13
	139.16	212.95	53.02	
	140.23	203.09	44.83	
30% B_3	134.56	197.08	46.46	45.67
	136.34	198.24	45.40	
	136.68	198.39	45.16	
40% B_3	132.84	199.19	49.95	50.72
	132.57	199.72	50.65	
	131.77	199.72	51.57	

Table B-9 Water Absorption of Lightweight Concrete for Different Percentage of Biomass Feed Recipe #4 Fly Ash Replacing Cement

Mix Destination	**Dry Weight (g)**	**Saturated Surface Weight (g)**	**Water Absorption (%)**	**Average Water Absorption (%)**
Control	142.32	196.11	31.12	38.30
	143.43	200.15	32.91	
	143.77	197.76	33.83	
5%B_3	146.88	207.66	41.38	39.29
	149.16	205.28	37.63	
	147.70	205.11	38.86	
10% B_3	145.57	201.73	38.58	39.42
	144.79	202.20	39.65	
	145.39	203.60	40.03	
15% B_3	142.60	200.54	40.63	41.27
	142.12	200.01	40.73	
	141.47	201.55	42.46	
20% B_3	140.52	199.89	42.25	43.86
	139.71	201.90	44.51	
	138.89	201.13	44.81	
30% B_3	137.02	201.04	46.72	47.07
	137.11	199.72	45.66	
	135.54	201.70	48.81	
40% B_3	133.09	199.96	50.24	52.35
	129.61	200.27	54.52	
	132.03	201.06	52.29	

Table B-10 Cost Computation for the Mix of 10% Rice Husk Fly Ash Replacing Portland Cement

Materials	**Amount used in the mix, W (kg/m^3)**	**Bulk specific gravity, G**	**Unit weight of material, γ (kg/m^3)**	**Volume of material, V V=W/ γ (m^3)**	**Amount used for a cubic meter of fresh concrete (kg/m^3)**	**Price/Unit (Baht)**	**Cost (Baht/m^3)**
Water	182.00	1.00	1000.00	0.1820	216.67	0.003	0.65
Cement	311.85	3.15	3150.00	0.0990	371.25	2.30	853.875
Rice husk fly ash	34.65	2.22	2220.00	0.0156	41.25	0.56	23.1
Lime	38.50	3.05	3050.00	0.0126	45.83	3.00	137.5
Sand	315.00	2.75	2750.00	0.1145	375.00	0.70	262.5
Aluminium powder	2.10	1.50	1500.00	0.0014	2.50	500	1250
Electricity	-	-	-	-	1.00	1050	1050
Total	884.10	13.67	13670.00	0.4252	-	-	3577.63

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 1055 m^3
= 0.8380 m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.8380 – 0.4252 m^3
= 0.4128 m^3 or 41.28% by volume of air

Table B-11 Cost Computation for the Mix of 20% Rice Husk Fly Ash Replacing Portland Cement

Materials	**Amount used in the mix, W (kg/m^3)**	**Bulk specific gravity, G**	**Unit weight of material, γ (kg/m^3)**	**Volume of material, V $V=W/\gamma$ (m^3)**	**Amount used for a cubic meter of fresh concrete (kg/m^3)**	**Price/Unit (Baht)**	**Cost (Baht/m^3)**
Water	182.00	1.00	1000.00	0.1820	236.36	0.003	0.71
Cement	277.20	3.15	3150.00	0.0880	360.00	2.30	828.00
Rice husk fly ash	69.30	2.22	2220.00	0.0312	90.00	0.56	50.40
Lime	38.50	3.05	3050.00	0.0126	50.00	3.00	150.00
Sand	315.00	2.75	2750.00	0.1145	409.09	0.70	286.36
Aluminium powder	2.10	1.50	1500.00	0.0014	2.73	500	1363.64
Electricity	-	-	-	-	1.00	1050	1050.00
Total	884.10	13.67	13670.00	0.4298	-	-	3729.11

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 1145 m^3

= 0.7724m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.7724 – 0.4298m^3

= 0.3424 m^3 or 34.24% by volume of air

Table B-12 Cost Computation for the Mix of 30% Rice Husk Fly Ash Replacing Portland Cement

Materials	**Amount used in the mix, W (kg/m^3)**	**Bulk specific gravity, G**	**Unit weight of material, γ (kg/m^3)**	**Volume of material, V $V=W/\gamma$ (m^3)**	**Amount used for a cubic meter of fresh concrete (kg/m^3)**	**Price/Unit (Baht)**	**Cost (Baht/m^3)**
Water	182.00	1.00	1000.00	0.1820	221.95	0.003	0.67
Cement	242.55	3.15	3150.00	0.0770	295.79	2.30	680.32
Rice husk fly ash	103.95	2.22	2220.00	0.0468	126.77	0.56	70.99
Lime	38.50	3.05	3050.00	0.0126	46.95	3.00	140.85
Sand	315.00	2.75	2750.00	0.1145	384.15	0.70	268.90
Aluminium powder	2.10	1.50	1500.00	0.0014	2.56	500	1280.49
Electricity	-	-	-	-	1.00	1050	1050.00
Total	884.10	13.67	13670.00	0.4344	-	-	3492.22

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 1099 m^3

= 0.8186 m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.8186 – 0.4344 m^3

= 0.3938 m^3 or 39.38 % by volume of air

Table B-13 Cost Computation for the Mix of 40% Rice Husk Fly Ash Replacing Portland Cement

Materials	**Amount used in the mix, W (kg/m^3)**	**Bulk specific gravity, G**	**Unit weight of material, γ (kg/m^3)**	**Volume of material, V V=W/ γ (m^3)**	**Amount used for a cubic meter of fresh concrete (kg/m^3)**	**Price/Unit (Baht)**	**Cost (Baht/m^3)**
Water	182.00	1.00	1000.00	0.1820	200.00	0.003	0.60
Cement	207.90	3.15	3150.00	0.0660	228.46	2.30	525.46
Rice husk fly ash	138.60	2.22	2220.00	0.0624	152.31	0.56	85.29
Lime	38.50	3.05	3050.00	0.0126	42.31	3.00	126.92
Sand	315.00	2.75	2750.00	0.1145	346.15	0.70	242.31
Aluminium powder	2.10	1.50	1500.00	0.0014	2.31	500	1153.85
Electricity	-	-	-	-	1.00	1050	1050.00
Total	884.10	13.67	13670.00	0.4390	-	-	3184.43

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 1066 m^3
= 0.8294 m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.8293 – 0.4390 m^3
= 0.3954 m^3 or 39.54 % by volume of air

Table B-14 Cost Computation for the Mix of 10% Biomass Feed Recipe #3 Fly Ash Replacing Portland Cement

Materials	**Amount used in the mix, W (kg/m^3)**	**Bulk specific gravity, G**	**Unit weight of material, γ (kg/m^3)**	**Volume of material, V V=W/ γ (m^3)**	**Amount used for a cubic meter of fresh concrete (kg/m^3)**	**Price/Unit (Baht)**	**Cost (Baht/m^3)**
Water	182.00	1.00	1000.00	0.1820	239.47	0.003	0.72
Cement	311.85	3.15	3150.00	0.0990	410.33	2.30	943.76
BFR#3	34.65	2.24	2240.00	0.0155	45.59	0.56	25.53
Lime	38.50	3.05	3050.00	0.0126	50.66	3.00	151.97
Sand	315.00	2.75	2750.00	0.1145	414.47	0.07	290.13
Aluminium powder	2.10	1.50	1500.00	0.0014	2.76	500	1381.58
Electricity	-	-	-	-	1.00	1050	1050.00
Total	884.10	13.69	13690.00	0.4250	-	-	3843.69

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 1164 m^3

= 0.7593 m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.7593 – 0.4250 m^3

= 0.3345 m^3 or 33.45 % by volume of air

Table B-15 Cost Computation for the Mix of 20% Biomass Feed Recipe #3 Fly Ash Replacing Portland Cement

Materials	**Amount used in the mix, W (kg/m^3)**	**Bulk specific gravity, G**	**Unit weight of material, γ (kg/m^3)**	**Volume of material, V V=W/ γ (m^3)**	**Amount used for a cubic meter of fresh concrete (kg/m^3)**	**Price/Unit (Baht)**	**Cost (Baht)**
Water	182.00	1.00	1000.00	0.1820	224.69	0.003	0.67
Cement	277.20	3.15	3150.00	0.0880	342.22	2.30	787.11
BFR#3	69.30	2.24	2240.00	0.0309	85.56	0.56	47.91
lime	38.50	3.05	3050.00	0.0126	47.53	3.00	142.59
Sand	315.00	2.75	2750.00	0.1145	388.89	0.70	272.22
Aluminium powder	2.10	1.50	1500.00	0.0014	2.59	500	1296.30
Electricity	-	-	-	-	1.00	1050	1050.00
Total	884.10	13.69	13690.00	0.4295	-	-	3596.81

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 1094 m^3
= 0.8081 m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.8081 – 0.4295 m^3
= 0.3786 m^3 or37.86% by volume of air

Table B-16 Cost Computation for the Mix of 30% Biomass Feed Recipe #3 Fly Ash Replacing Portland Cement

Materials	**Amount used in the mix, W** **(kg/m^3)**	**Bulk specific gravity, G**	**Unit weight of material, γ** **(kg/m^3)**	**Volume of material, V** **$V=W/\gamma$** **(m^3)**	**Amount used for a cubic meter of fresh concrete** **(kg/m^3)**	**Price/Unit** **(Baht)**	**Cost** **($Baht/m^3$)**
Water	182.00	1.00	1000.00	0.1820	219.28	0.003	0.66
Cement	242.55	3.15	3150.00	0.0770	292.23	2.30	672.13
BFR#3	103.95	2.24	2240.00	0.0464	125.24	0.56	70.13
lime	38.50	3.05	3050.00	0.0126	46.39	3.00	139.16
Sand	315.00	2.75	2750.00	0.1145	379.52	0.70	265.66
Aluminium powder	2.10	1.50	1500.00	0.0014	2.53	500	1265.06
Electricity	-	-	-	-	1.00	1050	1050.00
Total	884.10	13.69	13690.00	0.4340	-	-	3462.80

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 1080 m^3
= 0.8186 m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.8186 – 0.4340 m^3
= 0.3842 m^3 or 38.42% by volume of air

Table B-17 Cost Computation for the Mix of 40% Biomass Feed Recipe #3 Fly Ash Replacing Portland Cement

Materials	**Amount used in the mix, W (kg/m^3)**	**Bulk specific gravity, G**	**Unit weight of material, γ (kg/m^3)**	**Volume of material, V V=W/ γ (m^3)**	**Amount used for a cubic meter of fresh concrete (kg/m^3)**	**Price/Unit (Baht)**	**Cost (Baht/m^3)**
Water	182.00	1.00	1000.00	0.1820	219.28	0.003	0.66
Cement	207.90	3.15	3150.00	0.0660	250.48	2.30	576.11
BFR#3	138.60	2.24	2240.00	0.0619	166.99	0.56	93.51
lime	38.50	3.05	3050.00	0.0126	46.39	3.00	139.16
Sand	315.00	2.75	2750.00	0.1145	379.52	0.70	265.66
Aluminium powder	2.10	1.50	1500.00	0.0014	2.53	500	1265.06
Electricity	-	-	-	-	1.00	1050	1050.00
Total	884.10	13.69	13690.00	0.4384	1065.18	-	3390.16

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 971 m^3

= 0.9105 m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.9105 – 0.4384 m^3

= 0.4715 m^3 or 47.15% by volume of air

Table B-18 Cost Computation for the Mix of 10% Biomass Feed Recipe #4 Fly Ash Replacing Portland Cement

Materials	**Amount used in the mix, W (kg/m^3)**	**Bulk specific gravity, G**	**Unit weight of material, γ (kg/m^3)**	**Volume of material, V V=W/ γ (m^3)**	**Amount used for a cubic meter of fresh concrete (kg/m^3)**	**Price/Unit (Baht)**	**Cost (Baht/m^3)**
Water	182.00	1.00	1000.00	0.1820	233.33	0.003	0.70
Cement	311.85	3.15	3150.00	0.0990	399.81	2.30	919.56
BFR#4	34.65	2.24	2240.00	0.0146	44.42	0.56	24.88
lime	38.50	3.05	3050.00	0.0126	49.36	3.00	148.08
Sand	315.00	2.75	2750.00	0.1145	403.85	0.70	282.69
Aluminium powder	2.10	1.50	1500.00	0.0014	2.69	500	1346.15
Electricity	-	-	-	-	1.00	1050	1050.00
Total	884.10	13.69	13690.00	0.4241	-	-	3772.06

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 1139 m^3

= 0.7762 m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.7762 – 0.4241 m^3

= 0.3521 m^3 or 35.21% by volume of air

Table B-19 Cost Computation for the Mix of 20% Biomass Feed Recipe #4 Fly Ash Replacing Portland Cement

Materials	**Amount used in the mix, W (kg/m^3)**	**Bulk specific gravity, G**	**Unit weight of material, γ (kg/m^3)**	**Volume of material, V V=W/ γ (m^3)**	**Amount used for a cubic meter of fresh concrete (kg/m^3)**	**Price/Unit (Baht)**	**Cost (Baht/m^3)**
Water	182.00	1.00	1000.00	0.1820	224.69	0.003	0.67
Cement	277.20	3.15	3150.00	0.0880	342.22	2.3	787.11
BFR#4	69.30	2.24	2240.00	0.0291	85.56	0.56	47.91
lime	38.50	3.05	3050.00	0.0126	47.53	3.00	142.59
Sand	315.00	2.75	2750.00	0.1145	388.89	0.7	272.22
Aluminium powder	2.10	1.50	1500.00	0.0014	2.59	500	1296.30
Electricity	-	-	-	-	1.00	1050	1050.00
Total	884.10	13.69	13690.00	0.4277	-	-	3596.81

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 1096 m^3
= 0.8067 m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.8067 – 0.4277 m^3
= 0.3790 m^3 or 37.90% by volume of air

Table B-20 Cost Computation for the Mix of 30% Biomass Feed Recipe #4 Fly Ash Replacing Portland Cement

Materials	Amount used in the mix, W (kg/m^3)	Bulk specific gravity, G	Unit weight of material, γ (kg/m^3)	Volume of material, V V=W/ γ (m^3)	Amount used for a cubic meter of fresh concrete (kg/m^3)	Price/Unit (Baht)	Cost (Baht/m^3)
Water	182.00	1.00	1000.00	0.1820	219.28	0.003	0.66
Cement	242.55	3.15	3150.00	0.0770	292.23	2.3	672.13
BFR#4	103.95	2.24	2240.00	0.0437	125.24	0.56	70.13
lime	38.50	3.05	3050.00	0.0126	46.39	3	139.16
Sand	315.00	2.75	2750.00	0.1145	379.52	0.7	265.66
Aluminium powder	2.10	1.50	1500.00	0.0014	2.53	500	1265.06
Electricity	-	-	-	-	1.00	1050	1050.00
Total	884.10	13.69	13690.00	0.4312	-	-	3462.80

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 1066 m^3
= 0.8294 m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.8294 – 0.4312 m^3
= 0.3954 m^3 or 39.54% by volume of air

Table B-21 Cost Computation for the Mix of 40% Biomass Feed Recipe #4 Fly Ash Replacing Portland Cement

Materials	**Amount used in the mix, W (kg/m^3)**	**Bulk specific gravity, G**	**Unit weight of material, γ (kg/m^3)**	**Volume of material, V V=W/ γ (m^3)**	**Amount used for a cubic meter of fresh concrete (kg/m^3)**	**Price/Unit (Baht)**	**Cost (Baht/m^3)**
Water	182.00	1.00	1000.00	0.1820	211.63	0.003	0.63
Cement	207.90	3.15	3150.00	0.0660	241.74	2.3	556.01
BFR#4	138.60	2.24	2240.00	0.0582	161.16	0.56	90.25
lime	38.50	3.05	3050.00	0.0126	44.77	3	134.30
Sand	315.00	2.75	2750.00	0.1145	366.28	0.7	256.40
Aluminium powder	2.10	1.50	1500.00	0.0014	2.44	500	1220.93
Electricity	-	-	-	-	1.00	1050	1050.00
Total	884.10	13.69	13690.00	0.4348	-	-	3308.53

The entity volume of concrete = Total weight of materials in the mix / Density of concrete (m^3) = 884.10 / 1032m^3
= 0.8567 m^3

The volume of air = Volume of concrete – Volume of all materials m^3 = 0.8567 – 0.4348 m^3
= 0.4219 m^3 or 42.19% by volume of air

BIOGRAPHY

Name: Mr. Chatri Saosub

Date of Birth: December 28, 1984

Nationality: Thai

University Education: 2002-2005 Bachelor Degree of Science in
Environmental Science,
Faculty of Science, Silpakorn University,
Nakornpathom, Thailand

Presentation:

Chatri Saosub and Manaskorn Rachakornkij. *Utilization of fly ash from biomass power plant lightweight concrete.* The Proceedings of 7th National Environmental Conference, March 12 -14, 2008, at Chulabhon Research Institute, Bangkok, Thailand, Organized by the Environmental Engineering Association of Thailand