# การหาลักษณะเฉพาะของซีเมนต์แผ่นเรียบที่ใส่เถ้าแกลบ

นายวรเชฐ สมบูรณ์นะ



วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

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CHARACTERIZATION OF FLAT SHEET CEMENT CONTAINING RICE HUSK ASH

Mr.Worrachead  Somboonna



A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Science Program in Ceramic Technology

Department of Materials Science

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

.................................................... Dean of the Faculty of Science

(Professor Supot Hannongbua, Ph.D.)

THESIS COMMITTEE

.................................................... Chairman

(Associate Professor Saowaroj Chuayjuljit)

.................................................... Thesis Advisor

(Associate Professor Supatra Jinawath, Ph.D.)

.................................................... Member

(Assistant Professor Sirithan Jiemsirilers, Ph.D.)

.................................................... Member

(Thanakorn Wasanapiarnpong, Ph.D.)

.................................................... Member

(Dujreutai Pongkao Kashima, Ph.D.)

วรเชฐ สมบูรณ์นะ : การหาลักษณะเฉพาะของซีเมนต์แผ่นเรียบที่ใส่เถ้าแกลบ (CHARACTERIZATION OF FLAT SHEET CEMENT CONTAINING RICE HUSK ASH) อ.ที่ปรึกษา: รศ.ดร.สุพัตรา จินาวัฒน์, 63 หน้า.

งานวิจัยนี้ได้นำเถ้าแกลบจากบริษัท มหพันธ์ ไฟเบอร์ซีเมนต์ มหาชน จำกัด (ซิลิกาแบบมีผลึก) และจากบริษัท เอที ไบโอ พาวเวอร์ จำกัด (ซิลิกาแบบอสัณฐาน) ไปหาส่วนประกอบของธาตุและเฟส โดยวิธี XRF และ XRD ตามลำดับ ในการทดลองได้นำเอาเถ้าแกลบในอัตราส่วนระหว่าง 10 – 25 เปอร์เซ็นต์ ผสมเป็นมอร์ตาร์กับปูนปอร์ตแลนด์ซีเมนต์ ประเภท 1 ทราย น้ำ และสารเติมแต่ง ขึ้นรูปเป็นลูกบาศก์ขนาด 2 นิ้ว หลังจากบ่มในน้ำในช่วงเวลา 3 – 28 วันแล้ว ชิ้นงานได้ถูกนำไปทดสอบหาความแข็งแรง และ หาเฟสที่เกิดขึ้นโดยกล้องจุลทรรศน์อิเลคตรอนแบบส่องกราด จากผลการทดลองพบว่าปริมาณน้ำที่ใช้ผสมจะมากตามอัตราส่วนเถ้าแกลบที่ใส่ลงไป ความแข็งแรงกดของชิ้นทดสอบที่ใส่เถ้าแกลบแหล่ง เอที ไบโอ พาวเวอร์ มากกว่าชิ้นทดสอบของซีเมนต์มาตรฐานและที่ใส่เถ้าแกลบจากแหล่งมหพันธ์ที่ทุกช่วงเวลาบ่ม อัตราส่วนเถ้าแกลบที่เหมาะสมที่สุดอยู่ในช่วง 15–20 เปอร์เซ็นต์ และความแข็งแรงกดที่ 28 วัน ที่สูงสุดได้จากชิ้นงานที่ใส่เถ้าแกลบจากแหล่ง เอที ไบโอ พาวเวอร์ 20 เปอร์เซ็นต์



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Rice husk ashes (RHA) from two local sources, Mahaphant Fibre-Cement Public Co., Ltd. (crystalline $SiO_2$ as cristobalite) and A.T. Bio Power Co., Ltd. (amorphous $SiO_2$), were characterized for chemical composition and mineral phases by XRF and XRD, respectively. Then 10 - 25 wt% of RHA were mixed with Portland cement (Type I), sand, water and plasticizer to form into 2-in cubes of mortar. After wet curing (3-28 d) the specimens were tested for compressive strength and morphologies of the hydrates were observed by SEM. Although the water demand to attain normal consistency increased with the content of RHA, it was found that the strengths of A.T. Bio Power RHA added cement mortars were respectively higher than those of reference cement mortars (Portland cement type I : sand : water) and Mahaphant RHA added cement mortars at all curing ages. The highest compressive strength obtained at 28 d was from 20 wt% A.T. Bio RHA added cement mortars. This suggested the optimal content of RHA be 15-20 wt%.


Department:.........Materials Science...........Student's signature Worrachead Somboonna

Field of study:.....Ceramic Technology.......Advisor's signature...........(Supatra)

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# CHAPTER 1
# INTRODUCTION

## 1.1 General

The processing of industry results in a large quantity of waste product, including gas, water and solid waste. Especially, an enormous quantity of rice husk ash (RHA) from industrial productions directly affects environment and storage. To protect environment and decrease waste products, finding an appropriate utilization of them is a must.

Rice husk ash is a solid waste product from the power generating industry which is suitable for recycling. It is well known that silica is included in rice husk (RH) since 1983 [Martin, J. I.,]. The desilication of rice husk and a study of the products obtained. The amount of silica in rice husk varies between 13 – 29 w% depending on geographic location. The ash contains 87 – 97 w% silica and some amount of organics, alkali oxide, and impurities (1).

Although there have been many research documents on the utilization of rice husk ash as either a filler or a substitute for Portland cement in concrete products for quite some time, the reformulation for any particular product or condition has to be done due to the difference in the nature of the as-received rice husk ash, Portland cement and other components.

In order to find out the optimal weight ratio of rice husk ash - cement for a cement flat sheet or panel with a mechanical property, a range of test specimens containing various ratios of RHA substitute was prepared and their mechanical properties were investigated and measured according to ASTM C0109M-05(2). Some siliceous materials able to be hardened by the chemical reaction between silica and lime ($Ca(OH)_2$) forming silicates are called “Pozzolanas”(3) and the reaction is called “Pozzolanic reaction” This reaction is also beneficial to durability of concrete and to environment by decreasing rice husk ash pollution and saving sand reserve.

### 1.2 Objectives

1. Finding the optimal formulation for a flat sheet cement of which mechanical property matches the requirements of ASTM [4, 5] specification.
2. Decreasing pollution by utilizing waste (rice husk ash) from industry.

### 1.3 Scopes of the Study

The scope of this work covers the formulation of rice husk ash added cement mortars for use as building materials, i.e. flat sheet cement for panels. The specimens from a range of mix proportion are cured in water at scheduled ages. The hydrated specimens are characterized for mineralogical, physical and mechanical properties after which the optimal formula is deduced.

# CHAPTER 2

# THEORY

## 2.1 Background

Rice husk ash (RHA) is a by-product of rice husk (RH) production. Nowadays the RH produced more than 100,000,000 tons per year in the world. In Thailand about 5,000,000 tons of RH is produced every year. One utility of RH is biomass as energy source[6]. The heat energy is used for generating electricity.

## 2.2 Silica and rice husk ash

Dissolved silica can be taken up by a root from soil and concentrates in husk of rice. When dissolved silica was absorbed by a root and transported to husk, it accumulates and turns condensed silica in epidermis to form a silica double layer. In heat processing, rice husk is used as fuel and silica remains after the process.

## 2.3 Hydration of cement

The main reaction of cement with water is called "hydration". This reaction changes compound in cement into connective compound for improving mechanical properties in cement. These anhydrous compounds are $C_3S$, $C_2S$, $C_3A$ and $C_4AF$ when cement hydrating with water, 20 – 25 percentages of connective compounds, Calcium Silicate Hydrates ($3CaO.SiO_2.3H_2O$, C-S-H), and calcium hydroxide ($CaOH_2$) are formed.

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

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

Four main compounds in Portland cement when varied mechanical properties react with water display.

Tricalcium Silicate ($3CaO.SiO_2$, $C_3S$) has high strength at early time and is formed at high temperature.

Dicalcium Silicate ($2CaO.SiO_2$, $\beta$-$C_2S$) has high strength at later time and is formed at lower temperature.

Tricalcium Aluminate ($3CaO.Al_2O_3$, $C_3A$) has low strength at early time and the reaction with water is sudden.

Tetracalcium Aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$, $C_4AF$) has low strength after $C_3A$ and occurs at lower temperature than $C_3A$.

After reaction $C_3S$ and $C_2S$ contribute about 70 – 80 percentage mean strength index of hydrated cement(3).

### 2.4 Reaction between cement and silica

"Pozzolana" is called in case of the natural or artificial material containing silica in a reactive form. It is essential that pozzolana be in a finely divided state as it is only then that silica can combine with calcium hydroxide (liberated by the hydrating Portland cement) in the presence of water to form stable calcium silicates which have cementitious properties. Some pozzolanas may create problems because of their physical properties; e.g. porous form or very small silica particle (3).

### 2.5 Reaction between cement and rice husk ash

The rice husk ash concrete has higher mechanical properties in comparison with that of concrete without rice husk ash. At early ages residual rice husk ash provides a positive effect on the mechanical properties, but in the long term the behavior of the concretes with rice husk ash produced by controlled incineration was more significant(3).

### 2.6 Superplasticizer

Chemically, they are sulphonated melamine formaldehyde condensates and sulphonated naphthalene formaldehyde condensates, the latter being probably the somewhat more effective of the two in dispersing the cement and generally having also some retarding properties. The resulting concrete can be placed with little or no compaction and is not subject to excessive bleeding or segregation. Water/cement ratios down to 0 – 28 and the long-term strength is unimpaired, test results being available up to 13 years. Generally speaking, superplasticizers can reduce the water content for a given workability by 25 to 35 percents (compared with half that value in the case of conventional water-reducting admixtures), and increase the 24-hour strength by 50 to 75 percent, and even greater increase occurs at earlier ages.

The plasticizing action of superplasticizers is of short duration (perhaps 10 minutes): after some 30 to 90 minutes the workability returns to normal. For this reason, the superplasticizer should be added to the mix immediately prior to placing; usually, conventional mixing is followed by the addition of the superplasticizer and a short period of additional mixing. Superplasticizers can be used at high dosages. They do not markedly change the surface tension of water, their action being the dispersion of cement agglomerates normally found when cement is suspended in water. These admixtures are thought to be adsorbed on the surface of cement and of other very fine particles, causing them to become mutually repulsive as a result of the anionic nature of superplasticizers, which causes the cement particles to become negatively charged.

Superplasicizers do not significantly all affect. The only real disadvantage of superplasticizers is their relatively high cost[3].

**2.7 Literature reviews**

Loo Y.C., et. al. (1981) [7] studied about rice husk ash (RHA) as partial replacement in concrete. Also, they found the percentage replacement level of OPC by RHA was as high as 35 to 50%. In this category, 28 day strength of OPC/RHA concrete greater than that of the corresponding conventional concrete was achieved, but as in the first category, the water-cement ratio had to be kept low and equal to that of the conventional concrete. To make it as workable as the corresponding conventional concrete at this low water-cement ratio, the OPC/RHA concrete always required vibration. However where the water-cement ratio of the OPC/RHA concrete was increased over that of the conventional concrete to achieve equal workability without vibration the former, the strength of the former was lower than that of the latter.

Okpala, D.C. (1987) [8] studied about rice husk ash (RHA) as partial replacement in concrete, and he found the percentage replacement level of OPC by RHA was as high as 30 to 40 percentages for equal (medium) work ability and not requiring vibration. However the 28 day strength at the OPC/RHA concrete was lower than both specified design strength and the strength of the corresponding conventional concrete.

Yogananda M.R. and Jagadish K.S. (1989) [9] studied the pozzolanic properties of different types of rice husk ash, burnt clay (BC) and red mud (RM) under the influence of the compressive strength of lime-pozzolana mortar. Later, they discover the lime-pozzolana mortars using RHA, BC or RM as pozzolana satisfy the requirements for secondary construction applications like masonry and plastering. Also, the RHA samples, where the rice husk is burnt without utilizing its heat value, have lead to higher 28-day strength mortars. They attain 80 – 90 percentages the 28 day strength at the age of 7 days only. However, the long term strength results do not appear to be encouraging as there is a decrease in strength after 28 days. In case of RHA, where the heat from the husk has been utilized for producing hot water, the lime-RHA mortars have shown an increase in the long term strength. The 7 day strengths are however lower than in the earlier case. The reasons for these variations are yet to be fully understood. In addition, results of lime-RHA mortars with RHA containing mostly crystalline silica have shown that prolonged grinding of crystalline RHA enhances its lime-reactivity. The long term strength gain over 28 days is much higher than in case of other RHA samples. Besides, they found pregrinding of RHA before intergrinding with lime is essential to achieve higher strength mortars. And also, partial replacement of BC and RM by RHA greatly improves the compressive strengths of lime-BC and lime-RM mortars together.

Bogue R.H. (1989)[10] discovered the principal compounds in Portland cement are Tricalcium silicate ($3CaO.SiO_2$) which is chiefly responsible for initial setting and early strength of the cement water paste, dicalcium silicate ($2CaO.SiO_2$) which hardens slowly but contributes notably to strength at ages over a month. Equally it contains Tricalcium aluminate ($3CaO.Al_2O_3$) which liberates a large amount of heat during the first days of hardening and is rapidly attacked by sulphate solution, the iron-containing phase (a solid solution) that approaches the composition $4CaO.Al_2O_3.Fe_2O_3$ which is valuable as a flux in the many feature.

Ikpong A.A.and Okpala D.C. (1992) [11] studied to cover four grades of concrete (concrete having 28-day characteristic strengths of 20, 25, 30 and 40 $N/mm^2$) in the low and medium strength levels. The result of the majority of concrete-based construction work in this country utilizes concrete having 28-day strength of 30 $N/mm^2$ or below; therefore some cast savings can be achieved in the construction sector by substituting up to 40 percentages of the cement content of such works with rice husk ash. And this would be achieved of a work ability level that does not require the use of vibrators in placing the concrete. Rice husk ash therefore was the potential of ameliorating the dwindling building materials resource situation not only in Nigeria but in other developing countries where rice is grown.

Singh N.B., Bhattacharjee K.N. and Shukla A.K. (1995) [(12)] studied about hydration of Portland cement blended with granulated blast furnace slag and rice husk ash in presence of bag house dust has been studied by measuring non-evaporable water content, heat of hydration and compressive strengths. Also, they found the non-evaporable water content are always lower in presence of the waste materials as compared to the Portland cement, and BHD (Beg house dust) reduces the rate of heat evolution without affecting the hydration characteristics, whereas granulated blast furnace slag (GBFS) in presence of BHD retards the hydration of silicate phase and delays the conversion of ettringite to monosutphate. Rice husk ash on the other hand accelerates the hydration and increases the rate of heat evolution. Furthermore, BHD, GBFS and RHA-700 decreases the $Ca^{2+}$ ion concentrations in solution and the decrease is maximum in presence of RHA-700. Besides RHA-700 in combination with BHD gives maximum strength at 7 and 28 days of hydration, and it is possible to have better cements when appropriate proportions and added to the Portland cement.

Sugita S, Yu G, Shoya M, Tsukinage Y, and Isojime Y (1997) [(13)] studied the strengthening mechanism of RHA-blended concrete. They found the average pore size of RHA concrete, compared with that of control concrete, is decreased. Furthermore, the practical water-to-cement (w/c) ratio of RHA concrete is less than the used one because a portion of free water has been adsorbed in the great number of mesopores existing in RHA particles and length an average pore diameter of about 800 nanometers. And they discovered more C-S-H gel may be formed in RHA concrete due to the reaction that probably occurs between the silica in RHA and the $Ca^{2+}$, $OH^-$ ions, or $Ca(OH)_2$ in hydrating cement.

Awal and Hussin (1997) [(14)] reported that palm oil fuel ash had a good potential in suppressing expansion due to sulphate attack. In 2004, it was found that palm oil fuel ash, which contained a substantial amount of silica and was ground to a suitable fineness, could be used as a pozzolanic material to produce high strength concrete as high as 100 MPa at 90 days.

Gijun Yu, Sawayama K, Sugita S, Soya M and Isojima Y (1999) [15] studied the reaction between rice husk ash and $Ca(OH)_2$ solution at temperature around 40 degree Celsius and in the presence of water. They found rice husk ash (RHA) can react with $Ca(OH)_2$ to form one kind of fine C-S-H gel ($Ca_{1.5}.SiO_{3.5}.xH_2O$). The particle size of the reaction product, with an average diameter between 4.8 and 2.9 micrometers, varied slightly with the condition under which the reaction occurs. And, the C-S-H gel has a porous structure and large $N_2$ specific surface. The pores in the gel are mainly between 100 and 1000 nanometers with an average radius of about 200 nanometers. Besides, the main reasons in properties of concrete by adding RHA to concrete possibly may be attributed to the formation of more C-S-H gel and less portlandite in it due to the reaction occurring between RHA and the $Ca^{2+}$ and $H^-$ ions, or $Ca(OH)_2$ in hydrating cement. These properties of concrete improve strength and resistance to acid attack, carbonation, and penetration.

Ajiwe V.I.E., Okeke C.A. and Akigwe F.C. (2000) [16] used to produce cement from the agricultural waste, rice husk ash 24.5 percentages of rice husk ash (RHA) was mixed with other raw materials (sourced locally) for producing white Portland cement and bring it was tested for their physical characteristics and chemical composition. The results of tests appeared that produced cement was of similar standard to commercial cement. So, they cement can produce from rice husk ash that would help reduce problems of rice husks as farm wastes together.

Jauberthic R, Rendell F, Tamba S and Khalil Ciss'e I (2003) [17] studied properties of cement rice husk mixture by two rice husk ash samples, one year storage at 50% relative humidity (RH) and at 95% RH. This date reported the evolution of strength and physicochemical properties of light-weight mortars containing rice husks. The samples are conserved in air-conditioned rooms either of the ambient air temperature and 50% relative humidity (RH) or at 20 degree Celsius and 95% RH. This enables the study of the pozzolanic effect and the durability of cellulose fibre effect under different hygrometric conditions. X-ray diffraction analyses and SEM observations are used to observe physicochemical changes to the mortar. The results of the specimens have shown the importance of environmental conditions. At high humidity conservation the mortar gains strength by virtue of the well developed pozzolanic reaction; however, it becomes more brittle possibly due to the loss of the fiber reinforcement effect. The converse of this situation is found in the case of the specimens stored at 50% RH, i.c. lower compressive strength, higher flexural strength and increased elasticity. This study shows the importance of storage conditions on the behavior of lightweight rice husk mortar. To benefit from the fiber reinforcement in terms of improve flexural strength, the mortars must be used in conditions of high ambient humidity there will be a loss in flexibility, but offset against a gain in compressive strength.

Gemma Rodriguez de Sensale (2006)[18] studied on the development of compressive strength up to 91 days of concretes with rice-husk ash (RHA), in which residual RHA from a rice paddy milling industry in Uruguay and RHA produced by controlled incineration from the USA were used for comparison. Two different replacement percentages of cement by RHA, 10% and 20%, and three different water/cementicious material ratios (0.50, 0.40 and 0.32), were used. The results are compared with those of the concrete without RHA, with splitting tensile strength and air permeability. It is concluded that residual RHA provides a positive effect on the compressive strength at early ages, but the long term behavior of the concretes with RHA produced by controlled incineration was more significant. Results of splitting tensile and air permeability reveal the significant of the filler and pozzolanic effect for the concretes with residual RHA and RHA produce by controlled incineration.

# CHAPTER 3
# METHODOLOGY

## 3.1 Raw materials

### 3.1.1 Rice husk ash

In the experiment, approximately 50 kg of rice husk ash during the normal plant operation in June of 2006 was employed. The material were collected in a plastic bag and kept in a closed drum to prevent moisture in the air.

### 3.1.2 Portland cement

Type-1 Portland cement according to ASTM C150-95 [19] manufactured by TPI Ltd., Bangkok, Thailand, was used throughout the experiments.

### 3.1.3 Sand

River sand used for making specimen was natural silica sand that conformed to the requirements for graded sand as specified by ASTM C778-92 [20].

### 3.1.4 Water

Ordinary tap water was used for all mixed.

### 3.1.5 Superplasicizer

Solid Sodium-ortho-phenylphenol from BASF (Thai Ltd.)

## 3.2 Raw materials characterization

### 3.2.1 Specific gravity

Specific gravity is defined as the ratio of the weight of a given volume of specimen, including voids between the grains, to the weight of an equal volume of water. The procedure described in ASTM C188-95 [21] was used to determine specific gravity of Portland cement and adapted to calculate that of the rice husk ash. In the test for cement, kerosene (density 0.817 $g/cm^3$ at $60^o$ F) was used in place of water to ensure that all grains of the cement were wetted by the liquid and hydration was minimized.

### 3.2.2 Particle size distribution

As cement replacement material in the subsequent testing, Mahaphant RHA and AT Bio Power RHA were studied for size distribution. The ashes were subjected to particle size analysis by Laser scattering particle size analyzer (Malvern Instrument 2000). In this experiment, water was used as a medium with dispersing refractive index of 1.5.

### 3.2.3 Mineralogical composition by X-ray diffraction (XRD)

The powder X-ray diffraction (XRD) was used to identify mineralogical compositions of rice husk ash in terms of crystalline (Mahaphan RHA) and amorphous (AT Bio Power RHA) phases as shown in this figure. XRD patterns were obtained with a computer-controlled diffractometer (Bruker D8-Advance X-ray diffractometer) (Figure 3.1) equipped with a copper X-Ray tube and a scintillation detector. Monochromatic graphite was used to produce diffracted lines according to a single X-ray wavelength with low background. Samples were prepared by dehydration in an oven and grinding in agate mortar and pass the 100 mesh sieve. Operating conditions of the instrument were set at 40 kV accelerating voltage, 40 mA current, 0.02 step time, and two theta is from 10 to 80 degrees.


Figure 3.1 Bruker D8-Advance X-ray diffractometer

### 3.2.4 Elemental analysis by X-ray fluorescence (XRF)

The X-ray fluorescence (XRF) spectroscopy was carried out to measure bulk chemical compositions of both rice husk ash. This method provides useful information on the overall compositions of the analyzed materials. To obtain a good representative, the sample was initially ground in a ceramic mortar to achieve a homogeneous size of below 45 microns since the X-ray only penetrates up to a few millimeters from surface of a sample. With 1.5 grams of $H_3BO_3$ (2.5% by weight) binder, around 4.5 grams of ground sample was pressed into a pellet for convenient handling and measurement. Before running, the pilled sample was put in a sample cup and loaded on a feeder tray.

## 3.3 Specimen preparation for compressive strength test

Composition formulation and preparation of cement mortar (2 in cube). In this experiment the mixing was performed according to ASTM C305-99 [22]. About 650 grams of binder (cement), rice husk ash and sand were mixed with water and plasticizer [1 wt% of binder (cement or cement + ash)] to increase wetting of rice husk ash.

The amount of each ingredient required to make the mortar mixes for five cubes in each mix is given in Table 3.1.

Table 3.1 Compositions of the cement mortar

| Sample No. | Percentages of replacement | Mixed proportion by weight | | | | |
|---|---|---|---|---|---|---|
| | | Cement | Mahaphan RHA | AT Bio Power RHA | Sand | Percentage of plasticizer |
| 1 | 0 | 1.00 | - | - | 2.75 | - |
| 2 | 10 | 0.90 | 0.10 | - | 2.65 | 1 |
| 3 | 15 | 0.85 | 0.15 | - | 2.60 | 1 |
| 4 | 20 | 0.80 | 0.20 | - | 2.55 | 1 |
| 5 | 25 | 0.75 | 0.25 | - | 2.50 | 1 |
| 6 | 10 | 0.90 | - | 0.10 | 2.65 | 1 |
| 7 | 15 | 085 | - | 0.15 | 2.60 | 1 |
| 8 | 20 | 0.80 | - | 0.20 | 2.55 | 1 |
| 9 | 25 | 0.75 | - | 0.25 | 2.50 | 1 |

### 3.4 Normal consistency and setting time

The standard test method for normal consistency (ASTM C187-86 reapproved 1991) [23] and time of setting (ASTM C191-92) [24] of hydraulic cement by Vicat apparatus were used to characterize specimens from rice husk ash – cement pastes. About 650 grams of binder, or cement and rice husk ash, were mixed with water to form quickly into ball shape. The ball was put and pressed in a Vicat ring and then leveled carefully within 30 seconds after complete mixing. The amount of water in the paste shall be *normal consistency* when the 10 – mm plunger end of rod can penetrate to a point 10 $\pm$ 1 mm from the paste surface in 30 seconds after being released. *Initial setting time* is the time when a penetration of 1 mm Vicat needle is 25 mm after molding and remaining in the moist cabinet for 30 minutes.

### 3.5 Characterization of hydrated cement

#### 3.5.1 Bulk density

Bulk density of hydrated cement is defined as the weight of a given volume of specimen, including voids between the grains, The procedure described in ASTM C188-95 [21] was adopted for the rice husk ash-cement paste cubes in this experiment.

Also, bulk density can adapted into

$$D = W/(A \times B \times C)$$

By D = Specific gravity

W = Weight of dry specimen

A = Width of specimen

B = Long of specimen

C = Height of specimen

### 3.5.2 Phase analysis by X-ray diffraction (XRD)

The mineral phases of specimens with the best mechanical property of each batch, at 7 and 28 days were determined by XRD. Grinding specimen in an agate mortar to pass a 100 mesh sieve. Operating conditions of the instrument were set at 40 kV accelerating voltage, 40 mA current, 0.02 step time, and two theta is from 10 to 50 degrees.

### 3.5.3 Morphology of hydrated specimens

Microstructures of rice husk ash – cement specimens, 0, 15 and 25 percentages of rice husk ash at 7 and 28 days, were observed by scanning electron microscope (SEM).

### 3.5.4 Compressive strength of hydrated specimens

The procedures to measure compressive strength of hydraulic cement mortars are described in ASTM C109-95 (2). In this specification the water-to-binder ratio is kept constant because the variation in water-to-binder ratio could affect compressive strengths of mortars and reaction rate in the mixes. According to the requirement in ASTM C109-95 (2), the weight ratio of cement to sand is 1 : 2.75 and water to binder ratio is 0.485. Two-inch or 50-mm test cubes were prepared. The cubes were cured one day in the molds and then stripped and immersed in water until tested. Unconfined compressive strength tests were carried through mortar cubes at the age of 3, 7, 21 and 28 days. For each different levels of cement replacement, five specimens were prepared and tested so that the average would be reported.

In this experiment, both rice husk ashes directly replaced cement in the mixes by 0%, 10%, 15%, 20% and 25% by weight. Due to the difficulty in mixing and the hydrophobicity of the ash, the method was modified by varying water-to-binder ratio in the mixes in order to achieve the same flow for each formula of rice husk ash – cement paste. Hence, the flow was kept constant in this experiment.

# CHAPTER 4
# RESULTS AND DISCUSSIONS

## 4.1 Raw materials characterization

### 4.1.1 Specific gravity

ASTM Standard C188-95 [21] deals with specific gravity determination in cement. Portland cement, Mahaphant and A.T. Bio Power rice husk ash were determined in the usual manner by displacement of liquid in density bottle using kerosene.

Specific gravities of Mahaphant, A.T. Bio Power rice husk ash and Portland cement are 1.95, 2.07 and 3.14, respectively. Specific gravity of ash directly influences unit weight of ash concrete. That is, when ash is introduced in concrete, unit weight of the ash concrete decreases due to the low density of the ash. The density of ash depends on the density of the minerals of which the ash is composed and also on the presence of porous particle (whose specific gravity may be less than 1). Grinding of material is another factor affecting specific gravity.

### 4.1.2 Particle size distribution

The particle size distribution of Mahaphant RHA and AT Bio Power RHA used to make ash-cement mortars in the following experiments were determind using a particle size analyzer. Figure 4.1 and 4.2 show particle size distribution curves of Mahaphant RHA and AT Bio Power RHA, the mean particle sizes of ashes were 504.8 and 67.6 microns, respectively.

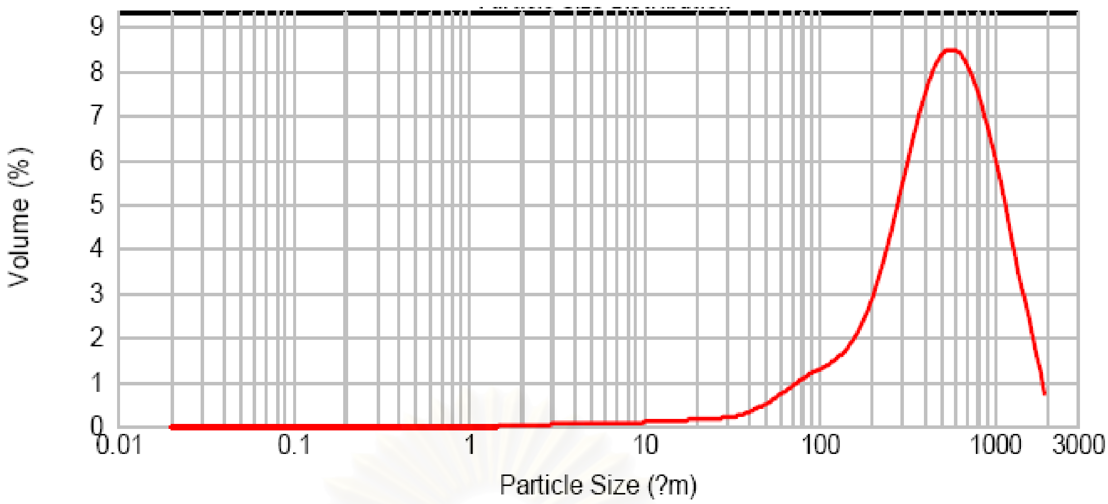


Figure 4.1 Particle Size Distribution and Cumulative Curves of Mahaphant RHA

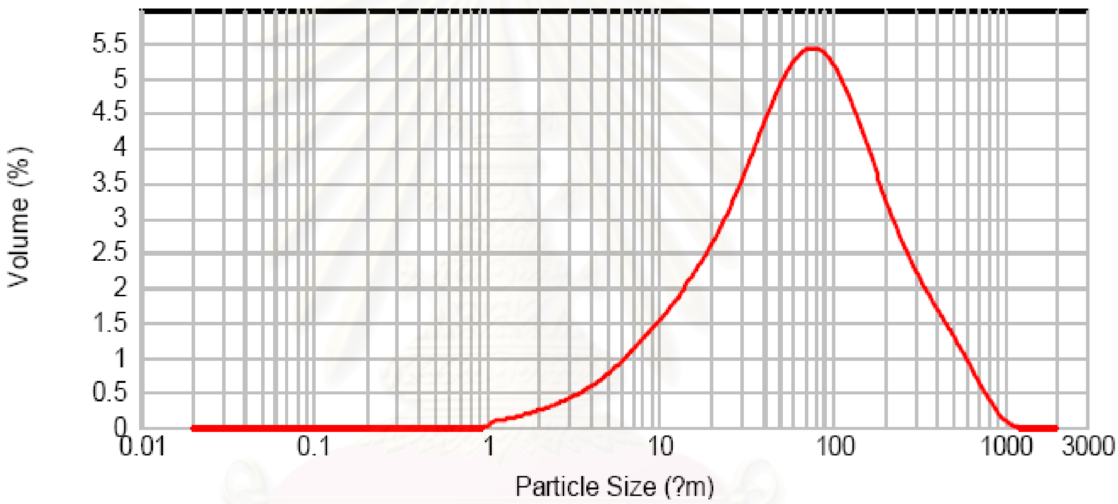


Figure 4.2 Particle Size Distribution and Cumulative Curves of AT Bio Power RHA

#### 4.1.3 Mineralogical composition

The crystalline phase of $SiO_2$ in Mahaphant rice husk ash observed by X-ray powder diffraction (XRD) spectrometer, Figure 4.3, is cristobalite. Figure 4.4 illustrates the XRD diffraction pattern of amorphous $SiO_2$ in A.T. Bio Power rice husk ash. The amorphous ash particles are usually composed of glassy phase reactive in concrete and responsible for the pozzolanic properties. That is the reason why A.T. Bio Power rice husk ash has been successfully utilized as a cement replacement material in construction applications. Figure 4.5 shows XRD diffraction pattern of ordinary Portland cement.

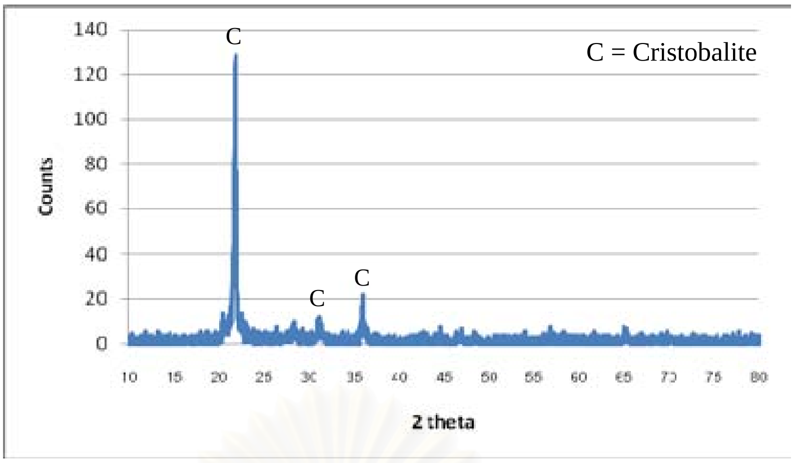


Figure 4.3 XRD Spectrum of Mahaphant rice husk ash

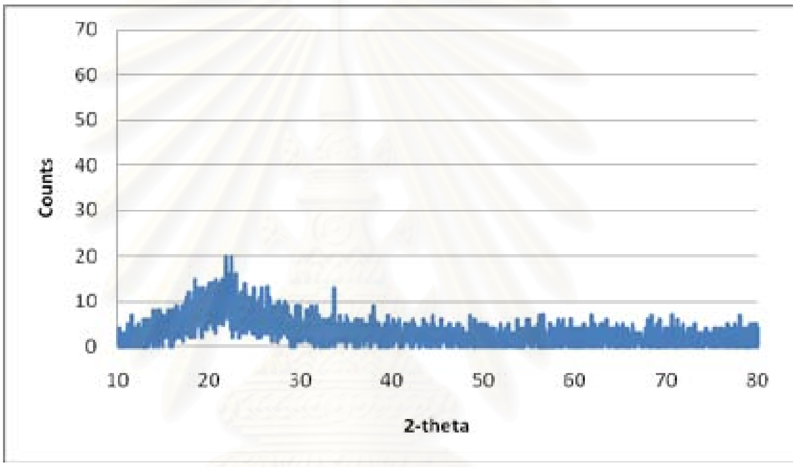


Figure  4.4 XRD Spectrum of A.T. Bio Power rice husk ash

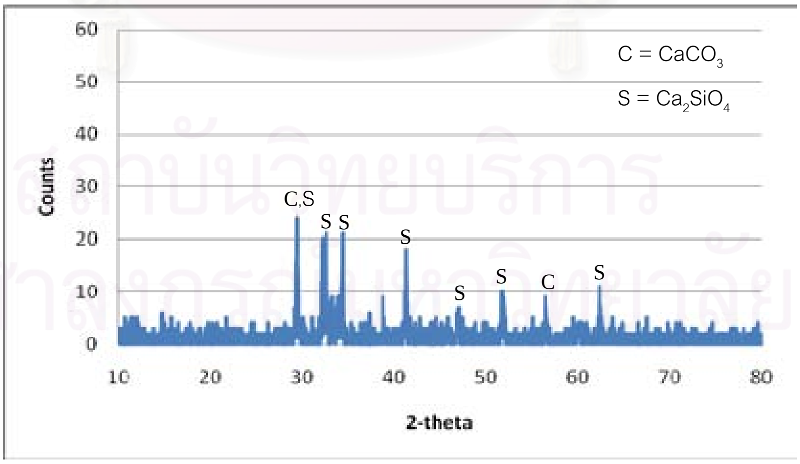


Figure  4.5 XRD Spectrum of Portland cement

#### 4.1.4 Bulk chemical composition

Table 4.1 shows chemical compositons of Portland cement, Mahaphant and A.T. Bio Power rice husk ash determined by X-ray fluorescence (XRF) spectroscopy, respectively. The analytical results of chemical compositions of all raw materials were given for comparison. All elemental compositions of these ashes were reported in oxide forms, the general format used in cement and concrete technology field. The table shows that chemical compositions Mahaphant and A.T. Bio Power rice husk ashes are insignificantly different. Thus, fractionation does not too much influence elemental compositions of the rice husk ash.

Table 4.1 Chemical Compositions of Mahaphant, A.T. Bio Power Rice Husk Ash and Portland Cement

| Compositions | Mahaphant Rice Husk Ash | A.T. Bio Power Rice Husk Ash | Portland Cement |
|---|---|---|---|
| $Fe_2O_3$ | 0.08 | 0.33 | 3.11 |
| $SiO_2$ | 75.84 | 81.54 | 15.54 |
| $Na_2O$ | 0.04 | 0.04 | 0.03 |
| MgO | 0.20 | 0.43 | 0.80 |
| $Al_2O_3$ | 0.10 | 0.46 | 3.61 |
| $P_2O_5$ | 0.42 | 1.12 | 0.06 |
| $SO_3$ | 0.04 | 0.55 | 2.70 |
| $K_2O$ | 1.55 | 2.66 | 0.31 |
| CaO | 0.52 | 0.87 | 58.63 |
| $TiO_2$ | 0.01 | 0.03 | 0.21 |
| $Cr_2O_3$ | - | - | 0.01 |
| MnO | 0.16 | 0.18 | 0.06 |
| ZnO | - | 0.0029 | 0.0033 |
| $Rb_2O$ | 0.01 | 0.01 | 0.0016 |
| SrO | 0.0036 | 0.0039 | 0.0307 |
| $ZrO_2$ | 0.0027 | 0.0029 | 0.0091 |
| $Nb_2O_5$ | - | - | 0.01 |
| $B_2O_3$ | - | 0.58 | - |
| Cl | 0.01 | 0.32 | - |
| L.O.I. | 21.00 | 10.88 | 14.88 |
| **Total** | **79.00** | **89.12** | **85.12** |

Oxides of Al, Ca, Fe, and Si in Mahaphant and A.T. Bio Power rice husk ash are interesting because they relate to the main compounds referred in Portland cement; namely, $C_3S$ (Tricalcium silicate), $C_2S$ (dicalcium silicate), $C_3A$ (Tricalcium aluminate), and $C_4AF$ (tetracalcium aluminoferrite). High amount of $SiO_2$ or silica in Mahaphant and A.T. Bio Power rice husk ash are 75.84 and 81.54, respectively. They were caused by nature of rice husk ash. For this reason, alkalis ($Na_2O$ and $K_2O$), chlorides (Cl), and sulphates ($SO_3$) in the both ashes were present lower 3 percentages. These alkaline compounds (although other alkalis also exist in the both ashes) have been found to react with some aggregates causing disintegration of concrete and to strongly affect the rate of strength gain beyond the age of 28 days in concrete. Low chloride such as sodium chloride would be additional source of alkalis in the both ashes. The use of such the both ashes in reinforced concrete should not be allowed because chlorides may lead to corrosion of steel. Moreover, the cause of false setting may be associated with alkalis in concrete ingredients. Since salts, particularly chlorides, in the ashes can be reached by water; ashes may be introduced as an additional material in concrete by simple process such as washing the ash with water.

### 4.2 Characterization of normal consistency and setting time

Normal consistency and setting time of Mahaphant and A.T. Bio Power rice husk ash added cement pastes analyzed using vicat apparatus according to the standard test methods described in the ASTM C187-86 [(23)] and ASTM C191-92 [(24)], respectively. Table 4.2 shows that water demand and setting time of ashes replacement. The influence of ashes on the properties of fresh concrete is also linked to the shape of ash particles. The increase in water requirement of ashes concrete caused by the presence of the ashes is usually associated with irregular and rough surface particles that absorb more water than the spherical shape. In this experiment, Mahaphant rice husk ash added cement pastes had required more water than another because of larger particle size and lower density of ash.

Initial setting time of A.T. Bio Power rice husk ash added cement pastes are lower than those of Mahaphant because particle size of A.T. Bio Power rice husk ash is smaller. Effect of this nature causes reaction between A.T. Bio Power and cement pastes is faster than Mahaphant – cement pastes. The shortest reaction time of both rice husk ash pastes is shown by 20 percentages added. Figure 4.6 and 4.7 show the plots between initial setting time of the cement pastes and the contents of Mahaphant and A.T. Bio Power rice husk ashes added, respectively.  Figure 4.8 shows the plots between the initial setting time of cement pastes containing 20 w% Mahaphant and A.T. Bio Power rice husk ashes and standard cement.  Figure 4.8 shows shorter reaction time of ash-cement over that of the standard cement because of the pozzolanic effect and A.T. Bio Power rice husk ash added cement had the lowest initial setting time due to its large surface area resulted from the smaller particle size.

Table 4.2 Water Requirement and Initial Setting Time of Mahaphant and A.T. Bio Power Rice Husk Ash with Cement Pastes

| Portland Cement | Mahaphant Rice Husk Ash | A.T. Bio Power Rice Husk Ash | Plasticizer (percentage) | Water Requirement | Initial Setting Time (min) |
|---|---|---|---|---|---|
| 1.00 | - | - | - | 0.25 | 115 |
| 0.90 | 0.10 | | - | 0.29 | 141 |
| 0.80 | 0.20 | | - | 0.39 | 98 |
| 0.70 | 0.30 | | 1 | 0.54 | 176 |
| 0.90 | - | 0.10 | - | 0.32 | 91 |
| 0.80 | - | 0.20 | - | 0.39 | 61 |
| 0.70 | - | 0.30 | 1 | 0.47 | 77 |

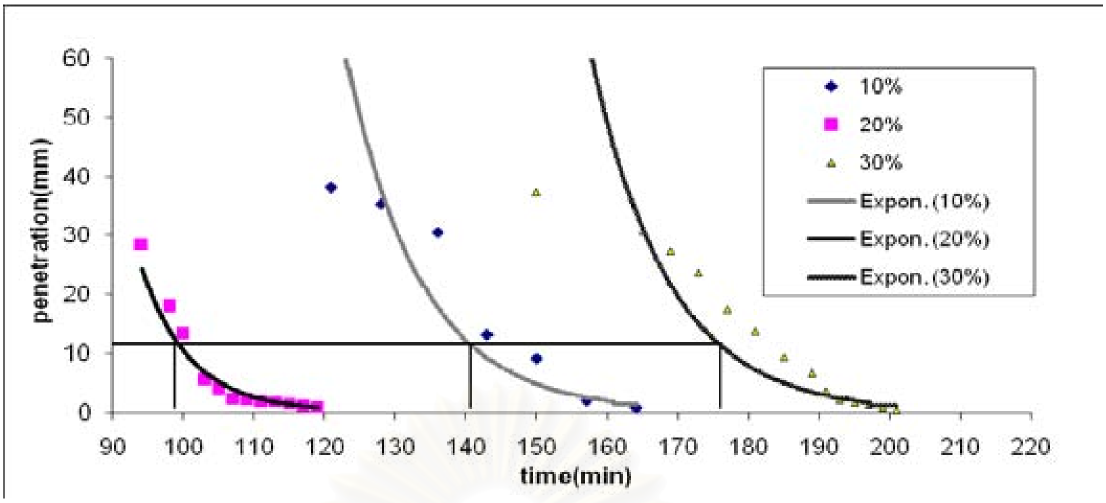


Figure 4.6 Plot between initial setting time and Mahaphant rice husk ash content

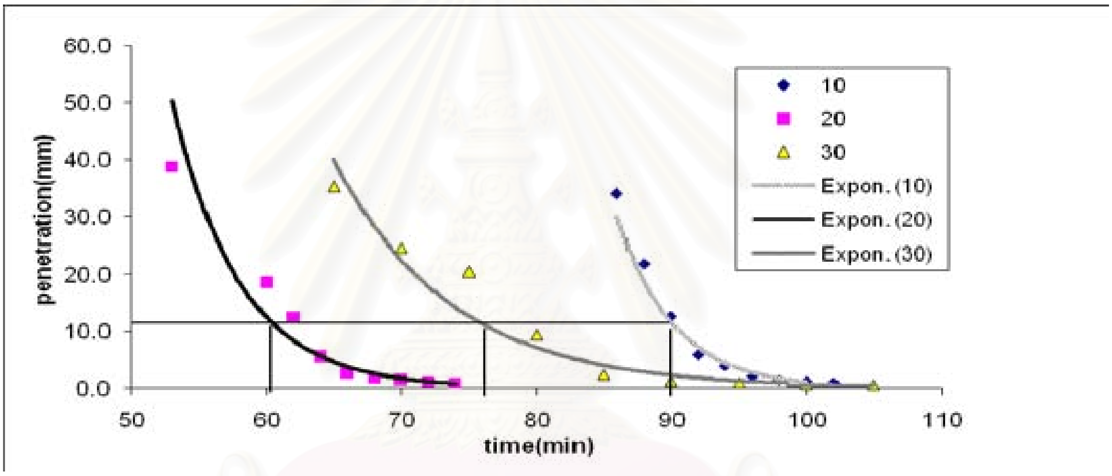


Figure 4.7 Plot between initial setting time and A.T. Bio Power rice husk ash content

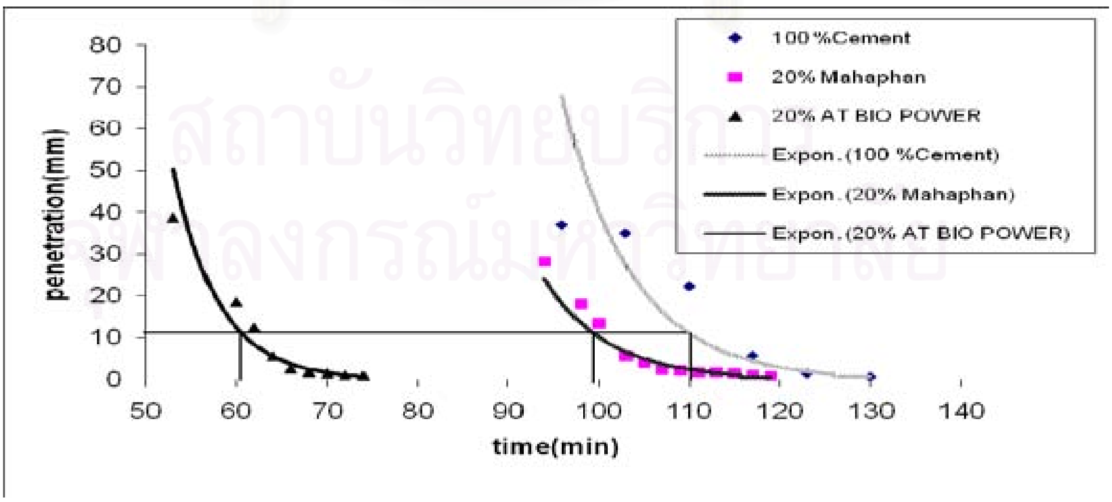


Figure 4.8 Plot between initial setting time of 20 w% Mahaphant, A.T. Bio Power rice husk ashes added and standard cement

## 4.3 Characterization of hydrated cement

### 4.3.1 Bulk density

From the result in Table 4.3, the bulk density of hydrated cement mortar at the same curing time is higher than those of the rice husk ash added cement mortars. The more rice husk ash is added to the mortar, the lower bulk density of the mortar is. This is due to the lower specific gravity of the ashes (1.95 and 2.07) when compared to Portland cement powder (3.14).

Table 4.3 Bulk density of hydrated cement.

| Cement | Sand | Mahaphant Rice Husk Ash | A.T. Bio Power Rice Husk Ash | Water | Bulk Density | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 3 days | 7 days | 21 days | 28 days |
| 1.00 | 2.75 | - | - | 0.35 | 2.11 | 2.03 | 2.05 | 2.05 |
| 0.90 | 2.65 | 0.10 | - | 0.35 | 1.94 | 1.93 | 1.95 | 1.97 |
| 0.85 | 2.60 | 0.15 | - | 0.45 | 1.91 | 1.92 | 1.92 | 1.89 |
| 0.80 | 2.55 | 0.20 | - | 0.45 | 1.84 | 1.93 | 1.94 | 1.94 |
| 0.75 | 2.50 | 0.25 | - | 0.65 | 1.83 | 1.84 | 1.90 | 1.89 |
| 0.90 | 2.65 | - | 0.10 | 0.35 | 1.98 | 2.07 | 1.97 | 1.97 |
| 0.85 | 2.60 | - | 0.15 | 0.40 | 2.00 | 1.95 | 2.02 | 2.02 |
| 0.80 | 2.55 | - | 0.20 | 0.45 | 2.06 | 1.94 | 2.01 | 2.00 |
| 0.75 | 2.50 | - | 0.25 | 0.50 | 1.90 | 1.93 | 1.95 | 1.95 |

4.3.2 Mineralogical compositions

The crystalline phases of 7 days of hydrated cement mortar observed by X-ray powder diffraction (XRD) spectrometer are shown in Figure 4.9. The detected components in crystalline phases of the hydrated standard cement mortar were α-quartz ($SiO_2$ from sand, ~21, 26.7$^{o}$ 2θ), Calcium Silicate Hydrate (CSH, ~30$^{o}$ 2θ), Portlandite ($Ca(OH)_2$,18, 34, 47$^{o}$ 2θ), Ettringite (9, 16, 42$^{o}$ 2θ), unreacted cement compounds (30-34$^{o}$ 2θ), i.e. alite ($C_3S$), belite( β-$C_2S$) $C_3A$ and $C_4AF$. At 28 days (Fig. 4.9), the phases of the hydration product are the same as those of 7 days but the unreacted cement compounds decrease.

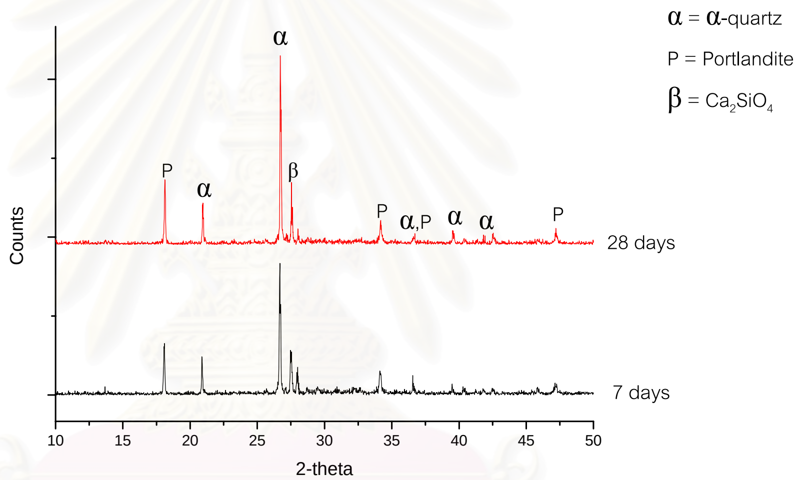


Figure 4.9 XRD Spectrum of hydrated cement mortar at 7 and 28 days

Fig.4.10 show the XRD spectra of 15 wt% Mahaphant rice husk ash added cement mortar at 7and 28 days, respectively. It is found that the phases of the hydration product are the same as those of the standard cement mortar, except the existence of cristobalite (~22$^{o}$ 2θ). The intensity of portlandite at 28 d is higher than that of 7 d which means that the progress of hydration has progressed.

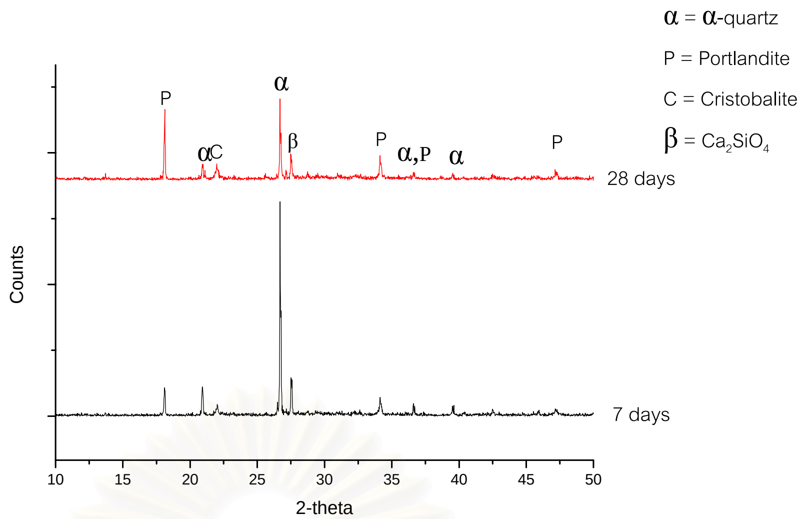


Figure 4.10 XRD Spectrum of hydrated 15 wt% of Mahaphant rice husk ash added cement mortar at 7 and 28 days

The XRD patterns of Fig. 4.11 show the mineral phases of the hydration product of 15 wt% AT Bio Power rice husk ash added cement mortars at 7 and 28 days. They are the same as those of Mahaphant cement mortars, but no existence of cristobalite (~22° 2θ).

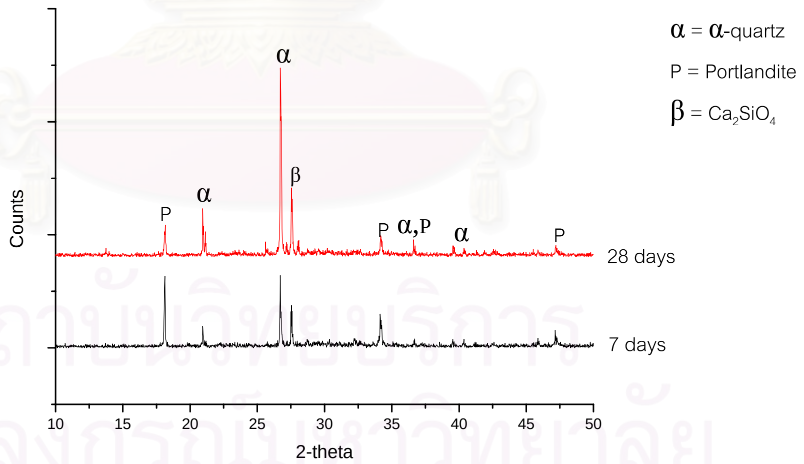


Figure 4.11 XRD Spectrum of hydrated 15 wt% of A.T. Bio Power rice husk ash added cement mortar at 7 and 28 days

With the increase of RHA to 25 Wt%, Fig. 4.12 and 4.13, the hydration product of Mahaphant and A.T. Bio Power rice husk ashes added cement mortars at 28 days. It is noticed that the content of portlandite in Mahaphant mortar is very high but much lower in the case of A.T. Bio Power rice husk ash. This is because portlandite is consumed faster and larger amount of C-S-H is produced.

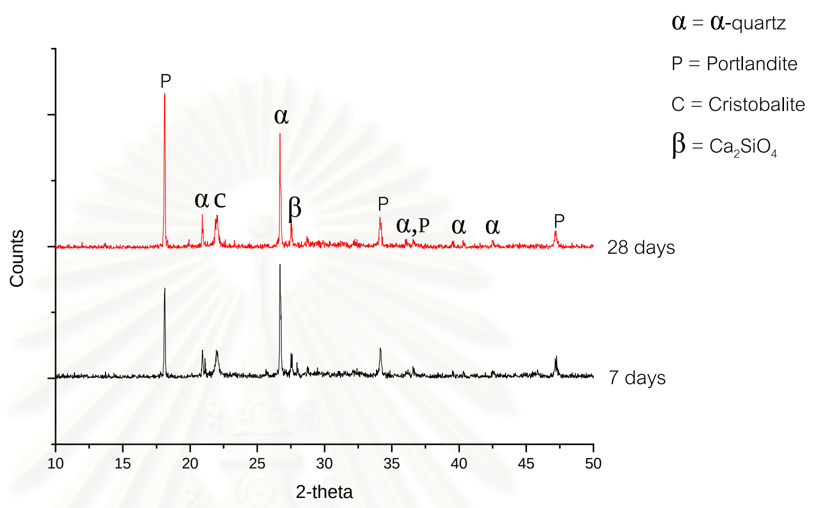


Figure 4.12 XRD Spectrum of hydrated 25 wt% of Mahaphant rice husk ash added cement mortar at 7 and 28 days

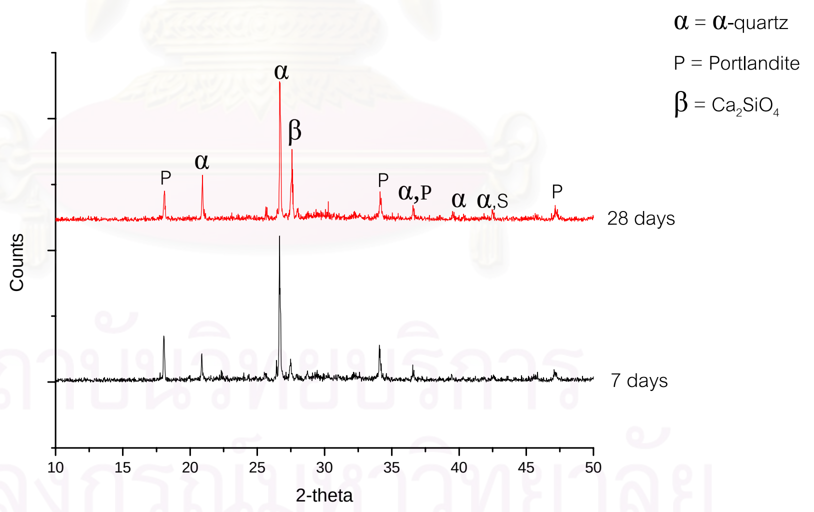


Figure 4.13 XRD Spectrum of hydrated 25 wt% of A.T. Bio Power rice husk ash added cement mortar at 7 and 28 days

4.3.3 Morphology

Scanning electron micrographs of standard cement mortar or control at 1000x at 7 days, Figure 4.14 (a) shows densification of hydrated cement mortar and at 20000x at 7 days, Figure 4.14 (b), shows formation of C-S-H on the sand grains and pores. The SEM micrographs of hydrated cement mortar at 28 days at 1000x and 20000x in Figure 4.15 (a) and 4.15 (b) show more C-S-H as very long lath like particles and micro pores in hydrated cement.

For 15 wt% hydrated Mahaphant rice husk ash added cement mortar at 7d, magnification 1000x and 10000x, Figure 4.16 (a) and 4.16 (b). These Figures show grains of rice husk ash in the matrix with hydration product coated. At higher magnification, 20000x, Figure 4.16 (c), fibers or laths of C-S-H are observed. Figure 4.17 (a), 4.17 (b) and 4.17 (c) show SEM of 15 wt% Mahaphant rice husk ash added cement mortar at 28 days at 1000x, 10000x, and 20000x, respectively. These figures reveal denser CSH as network of platy particles and micro pores.

The SEM of 15 wt% A.T. Bio Power rice husk ash added cement mortar at 7 days at 2000x and 20000x, Figure 4.18 (a) and 4.18 (b), show the hydration product of A.T. Bio Power mortar which is denser and finer grain than that of Mahaphant mortar (at the same ash content) due to the amorphous rice husk ash particle. The SEM at 28 days at 2000x and 20000x, Figure 4.19 (a), 4.19 (b) and 4.19 (c), respectively reveal the hydration product densely coated on the RHA grains.

The SEM of 25 wt% Mahaphant rice husk ash added cement mortar at 7 days at magnificent 2000x and 20000x were shown in Figure 4.20 (a) and 4.20 (b), respectively. These figures show more densification compare with 15 wt% ash due to more dispersion of rice husk ash in matrix and cubic crystals of cristobalite. The SEM at 28 days of reaction, at 2000x and 20000x, Figure 4.21 (a) and 4.21 (b), respectively, show cristobalite cubes, more plate-like CSH network and Portlandite ($Ca(OH)_2$) crystals.

Figure 4.22 (a) and 4.22 (b), 25 wt% A.T. Bio Power rice husk ash added cement mortar at 7 days at magnificent 2000x and 20000x, respectively, show densification of hydrates (CSH) and $Ca(OH)_2$. At 28 days, Figure 4.23 (a) and 4.23 (b), at magnificent 2000x and 20000x show denser network of C-S-H and more $Ca(OH)_2$ platy crystals. It is obvious that the reaction between amorphous $SiO_2$-$Ca(OH)_2$ is more intensive than crystalline $SiO_2$.

The EDS, Figure 4.24 shows quantitative results of elements in the control or standard hydrated cement mortar at 28 days at point 1 (fiber or lath), 2 (matrix) and 3 (small fiber), respectively. The EDS of all points show Ca, Si, and O, hence confirms the occurrence of CSH.

Form the results, the EDS of 15 wt% A.T. Bio Power rice husk ash added cement mortar at 28 days at point 1, 2, and 3 are shown in Figure 4.25. All points show C, O, Al, Si, and Ca which confirm the occurrence Portlandite , CSH, and calcium aluminate.

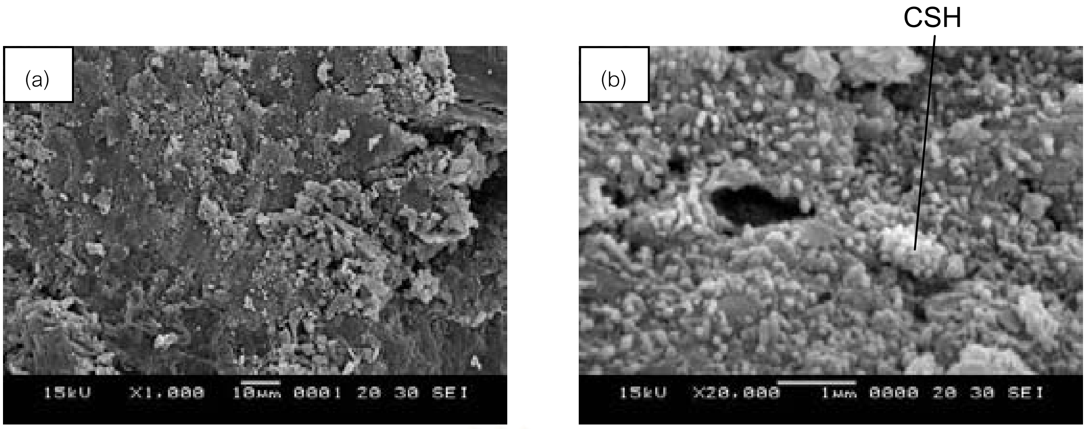


Figure 4.14 SEM photograph of Standard Cement 1000x (a) and 20000x (b) at 7 days

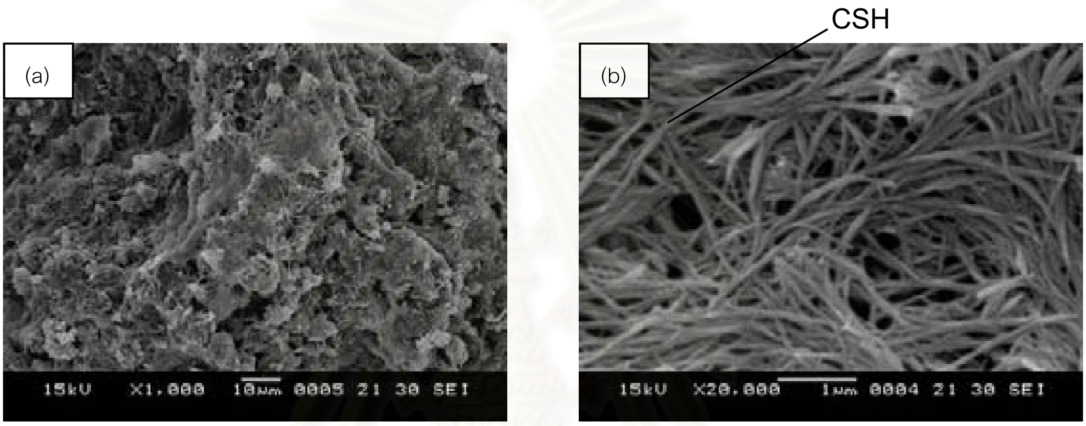


Figure 4.15 SEM photograph of Standard Cement 1000x (a) and 20000x (b) at 28 days

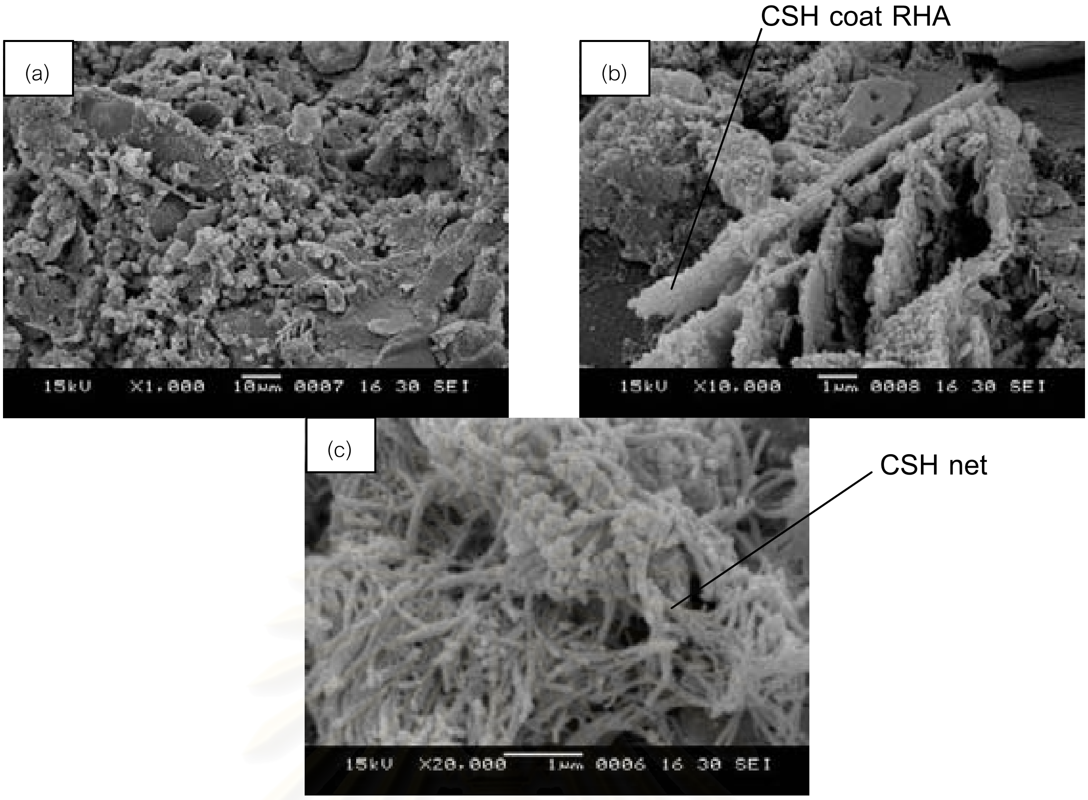


Figure 4.16 SEM photograph of 15 percentages of Mahaphant-Cement Mortar at 1000x (a), 10000x (b), and 20000x (c) at 7 days

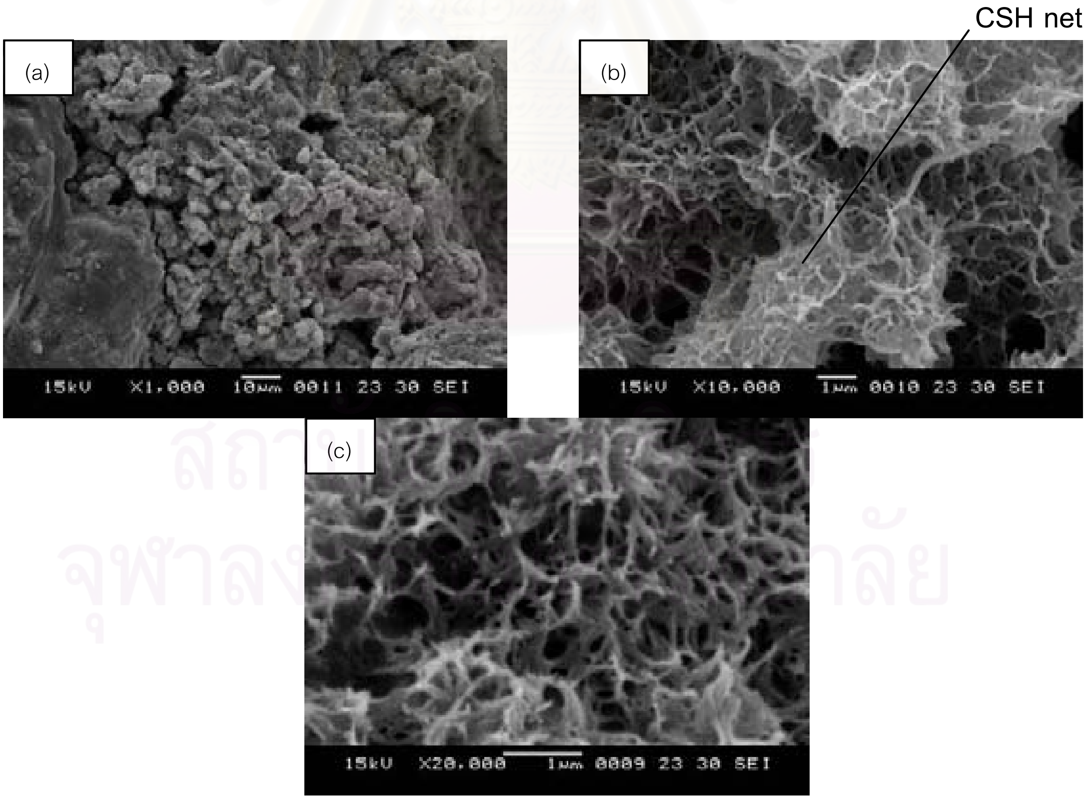


Figure 4.17 SEM photograph of 15 percentages of Mahaphant-Cement Mortar at 1000x (a), 10000x (b), and 20000x (c) at 28 days

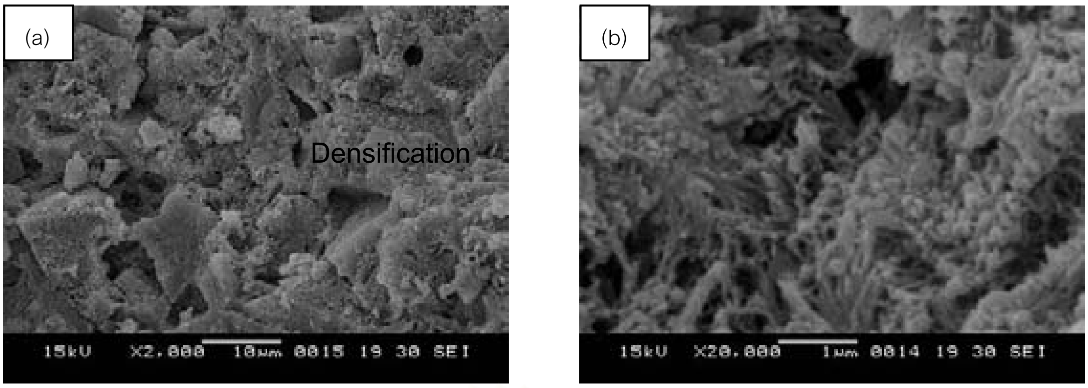


Figure 4.18 SEM photograph of 15 percentages of A.T. Bio Power-Cement 2000x (a) and 20000x (b) at 7 days

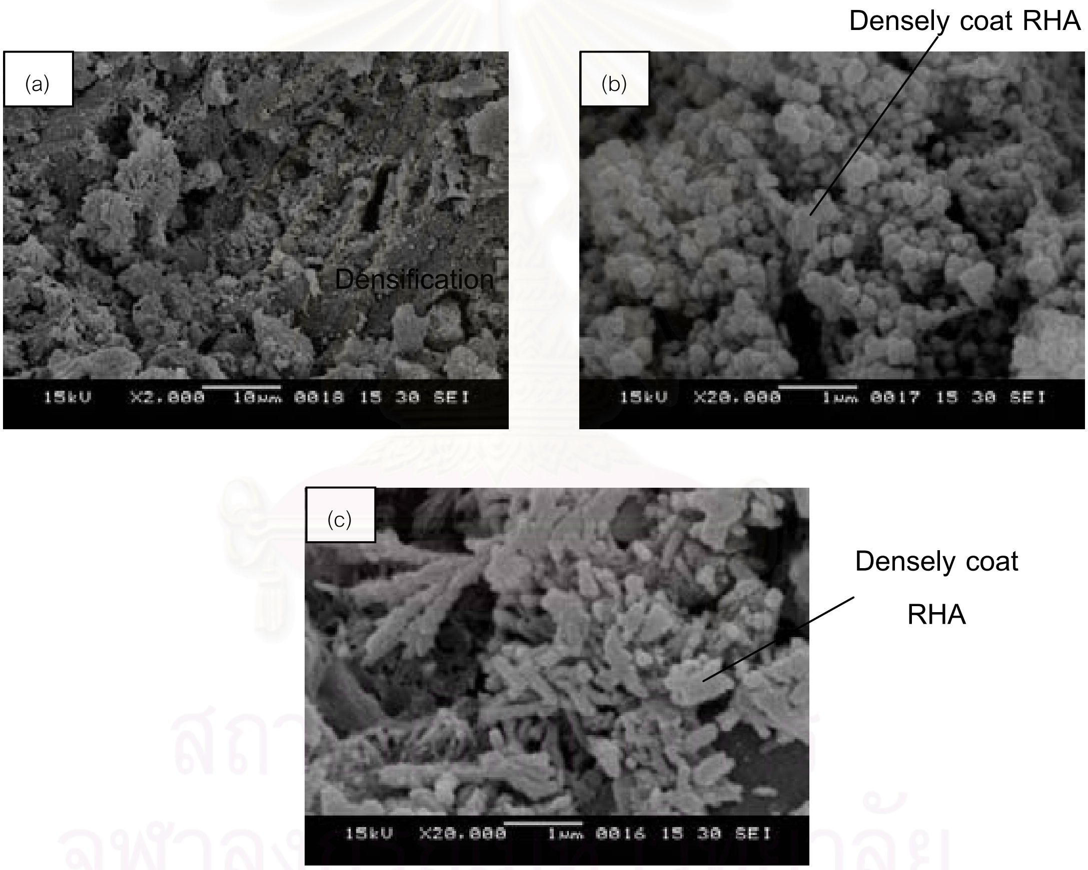


Figure 4.19 SEM photograph of 15 percentages of A.T. Bio Power-Cement 2000x (a) and 20000x (b), (c) at 28 days

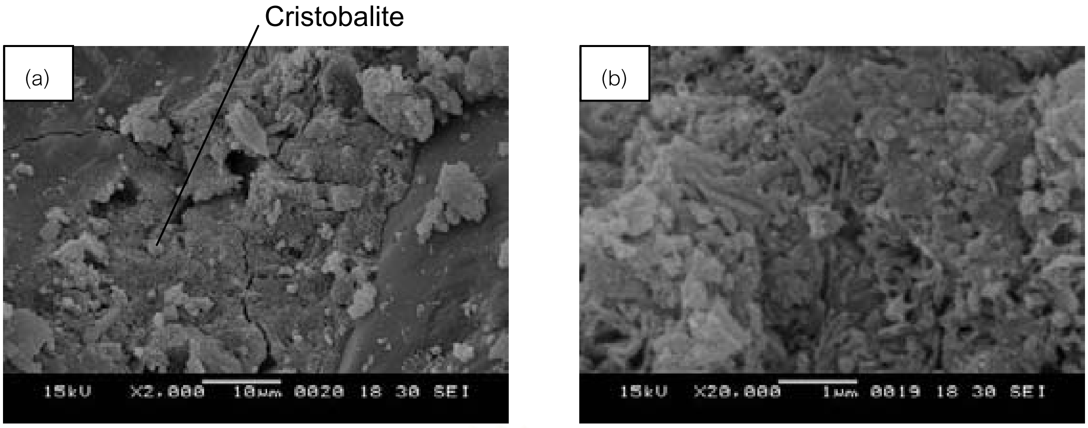


Figure 4.20 SEM photograph of 25 percentages of Mahaphant-Cement 2000x (a) and 20000 (b) at 7 days

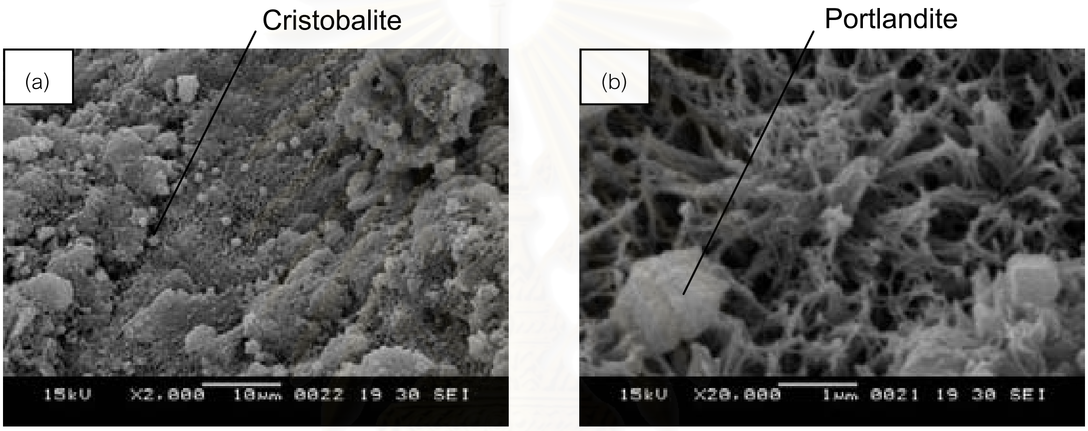


Figure 4.21 SEM photograph of 25 percentages of Mahaphant-Cement 2000x (a) and 20000x (b) at 28 days

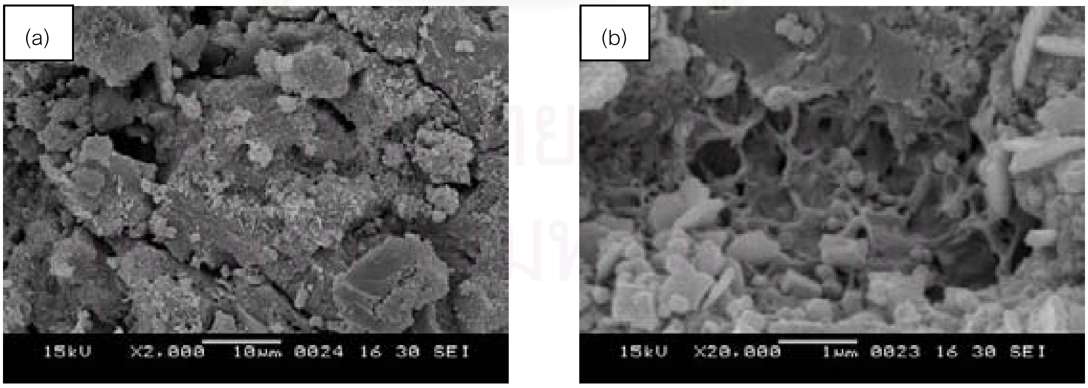


Figure 4.22 SEM photograph of 25 percentages of A.T. Bio Power-Cement 2000x (a) and 20000x (b) at 7 days

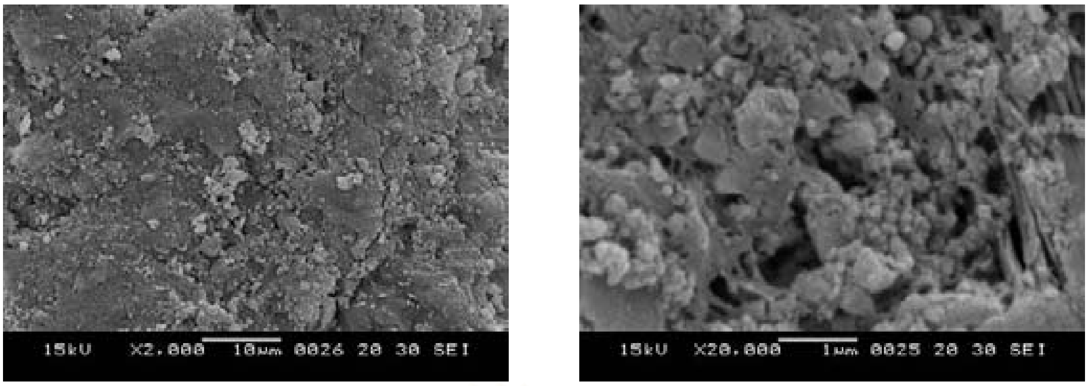


Figure 4.23 SEM photograph of 25 percentages of A.T. Bio Power-Cement

2000x (a) and 20000x (b) at 28 days

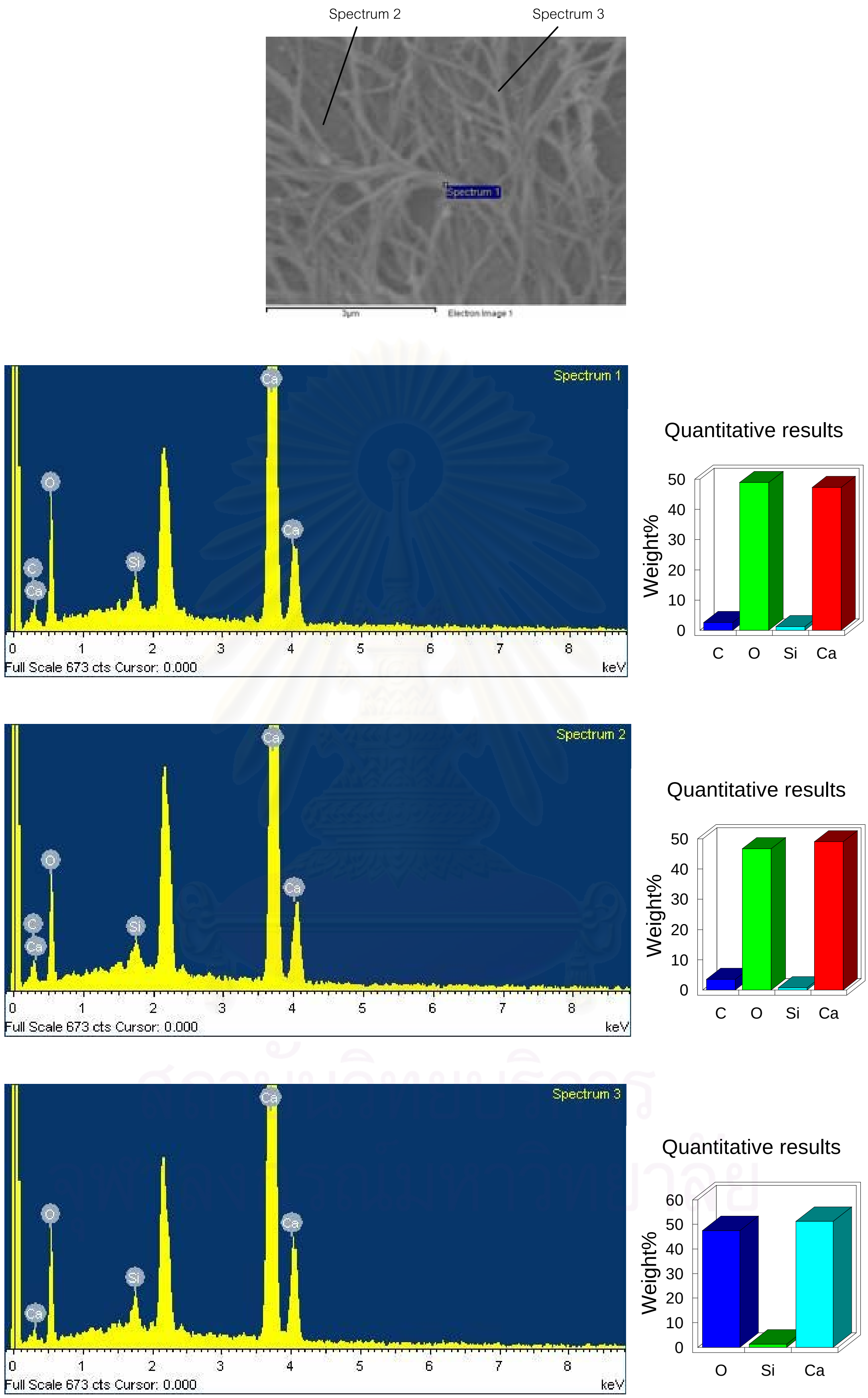


Figure 4.24 EDS of control Cement at 28 days

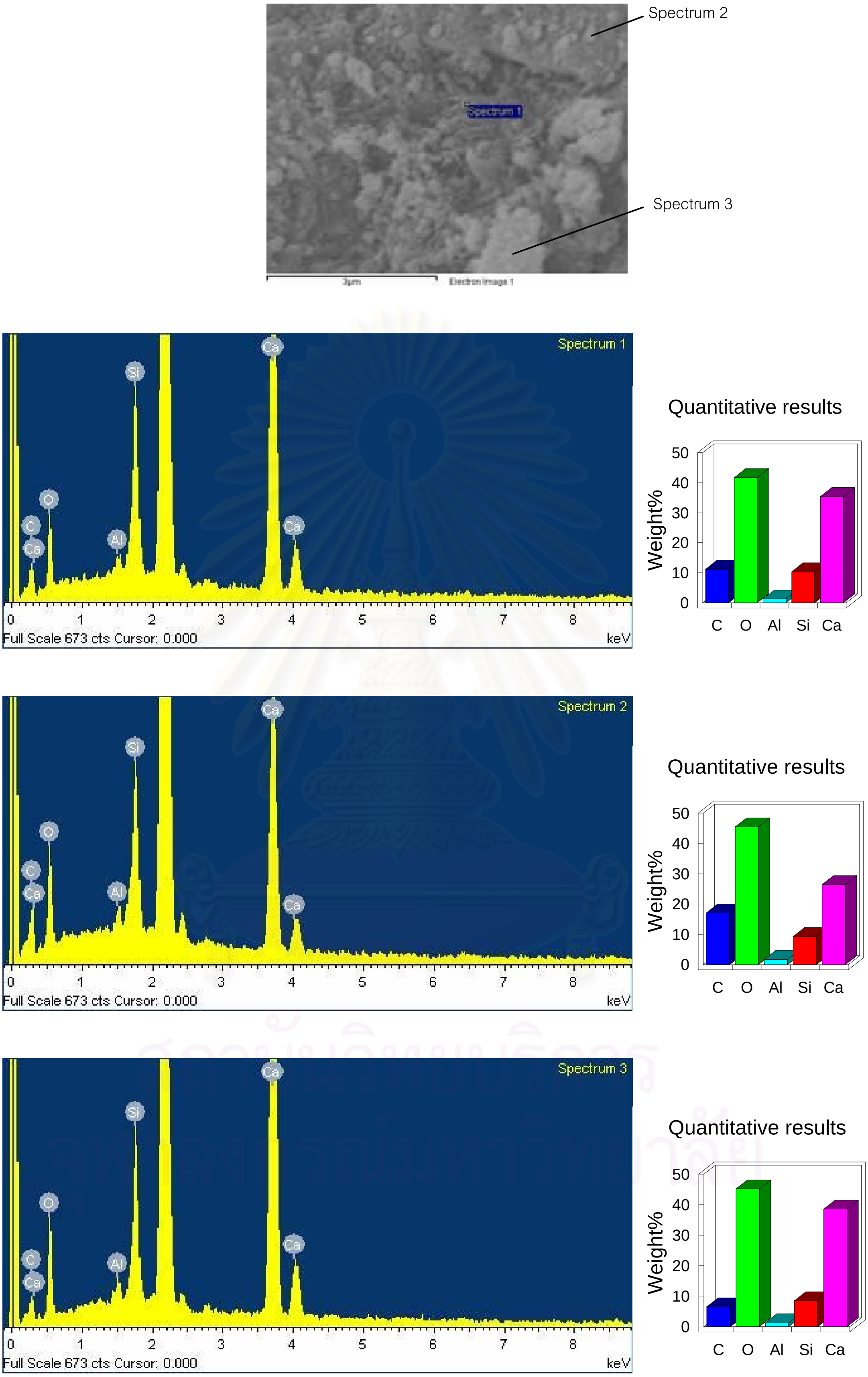


Figure 4.25 EDS of 15% AT Bio Power RHA-Cement at 28 days

4.3.4 Compressive strength

In this experiment, Mahaphant and A.T. Bio Power rice husk ashes were used as a replacement at 0, 10, 15, 20, and 25 percentages by weight of binders (cement + rice husk ash) to make rice husk ash mortar. The mix proportions of these mortars were mentioned in Table 3.1, but with modified water-to-binder ratio (>0.485) due to the increase in water demand. Figure 4.26 shows the effect of cement replacement by Mahaphant rice husk ash on compressive strength of mortar. It can be seen from the figure that all Mahaphant rice husk ash specimens show lower compressive strength than the control at the same age. The larger particle size and the crystalline $SiO_2$ of Mahaphant rice husk ash is less active than the amorphous $SiO_2$ of A.T. Bio rice husk ash, therefore Mahaphant rice husk ash is slow to react with lime and consequently results in porous structure. On the contrary, Figure 4.27 shows A.T. Bio Power rice husk ash at 15 and 20 wt% added have higher compressive strength than the control at the same age. The higher the percentage of A.T. Bio Power rice husk ash (25% or more) shows lower compressive strength compared with the control, Figure 4.28, because the available lime for the pozzolanic reaction does not match the excessive silica. Effect of this nature leads to low strength. The highest strength at 28 d is achieved at 20 wt% A.T. Bio Power RHA.

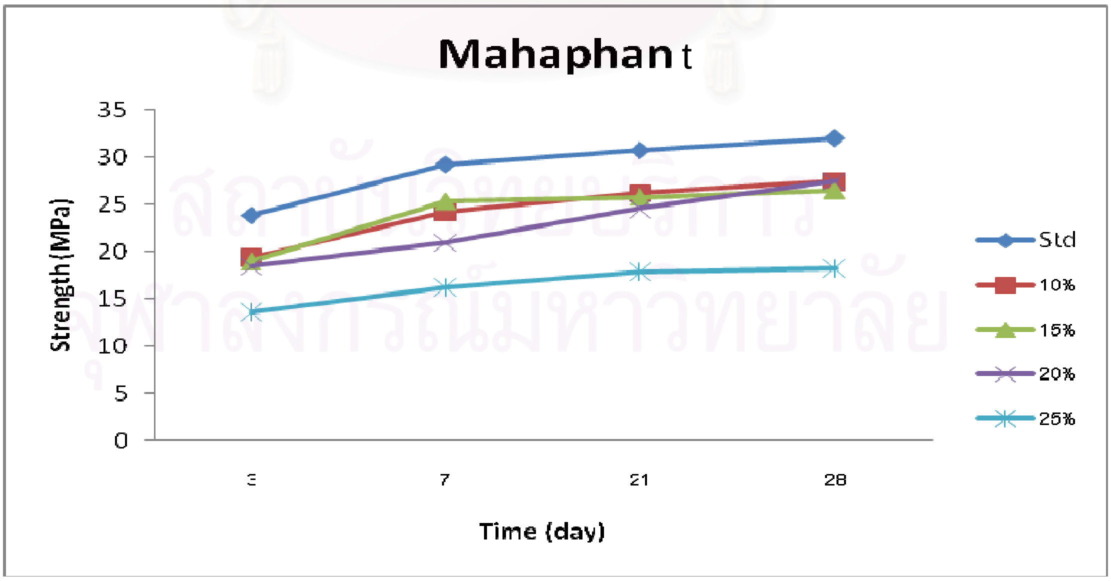


Figure 4.26 Compressive Strength of Mahaphant Rice Husk Ash with Cement Mortar at Different Percent Replacements

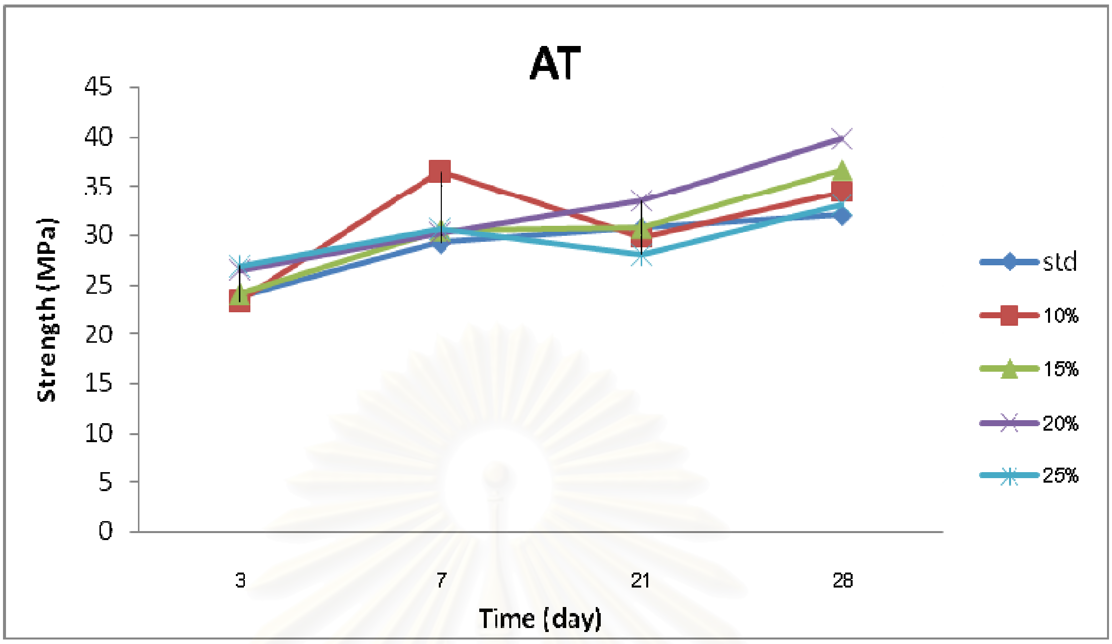


Figure 4.27 Compressive Strength of A.T. Bio Power Rice Husk Ash with Cement Mortar at Different Percent Replacements

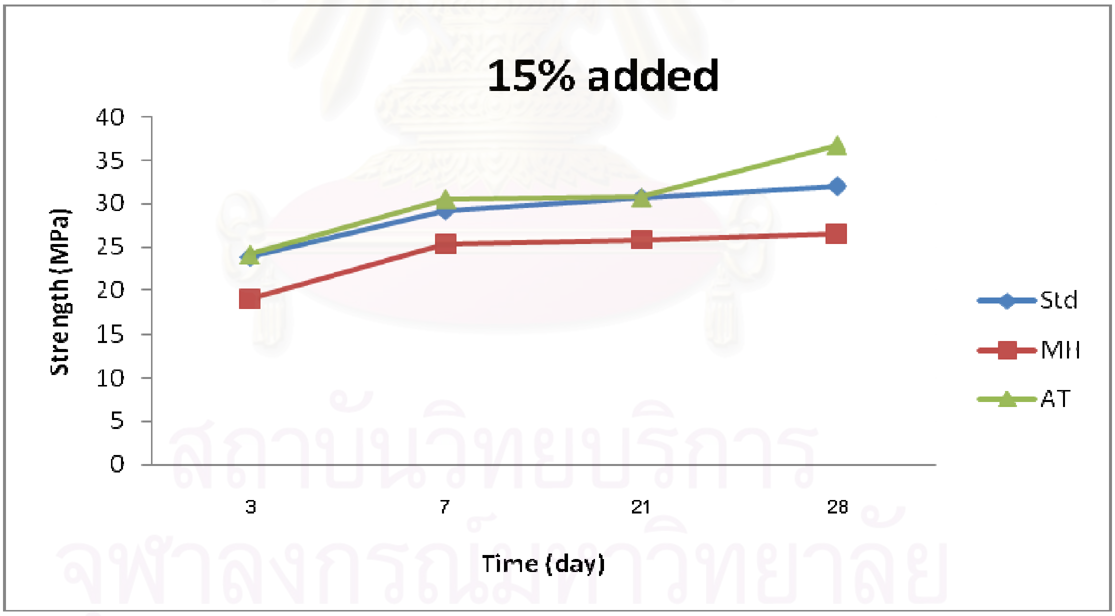


Figure 4.28 Compressive Strength of Mahaphant and A.T. Bio Power Rice Husk Ash with Cement Mortar at 15 Percent Replacements

# CHAPTER 5
# CONCLUSIONS AND SUGGESTIONS

The research was conducted to evaluate the potential of Mahaphant and A.T. Bio Power rice husk ashes as cement replacement material in cement flat sheet products. The effects of physical properties, chemical and mineralogical compositions of both rice husk ashes on cement mortars were investigated. The following conclusions could be drawn from this study:

## 5.1 Raw material characterization

The XRD analysis revealed the mineral phases in the as-received RHAs from Mahaphant fibre-cement public Co. ltd. and AT Bio Power Co. ltd. as cristobalite and amorphous $SiO_2$, respectively. The chemical compositions by XRF of Mahaphant and AT Bio Power RHAs also revealed low $P_2O_5$, $K_2O$ and CaO and high $SiO_2$ which made them suitable for pozzolanic material according to the ASTM C618 requirements. Initial setting times of all the RHA added cement pastes were shorter than the reference cement paste while normal consistency was higher. A.T. Bio Power RHA-cement paste showed shorter setting time than that of Mahaphant RHA, especially 20 wt% A.T. Bio Power RHA added. Investigation on normal consistency showed the requirement of water to initiate the flow of the paste increased with increasing content of RHA.

## 5.2 Characterization of hydrated cement

15-20 wt% A.T. Bio Power rice husk ash added cement mortars respectively gave higher compressive strength than the reference cement mortars and Mahaphant RHA added cement mortars at all curing time. Over 20 wt% RHA added lowered the strength due to the excessive $SiO_2$. Therefore the optimal formulation was suggested at 15-20 wt% A.T. Bio Power rice husk ash added.

## 5.3 Suggestions for future works

1. Mahaphant RHA should be ground to smaller grain for a better pozzolanic reaction.

2. Properties of all rice husk ash should be enhanced to suit concrete applications such as washing with water or acid solution, firing to remove excess carbon.

3. Using the mixture of RHAs that contain crystalline and amorphous $SiO_2$.

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# APPENDICES

Appendix (a) Data of hydrated cement at 3 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 49.5 | 51.6 | 51.3 | 257.50 | 6800 | 26.1 | 131.03 | 1.97 | 680.71 | 696.26 | 870.91 | 13.22 |
| 2 | 46 | 50.5 | 51.6 | 253.83 | 6400 | 27.0 | 119.87 | 2.12 | 728.98 | | | |
| 3 | 48.7 | 51.7 | 51.1 | 260.54 | 6700 | 26.1 | 128.66 | 2.03 | 680.08 | | | |
| 4 | 47.7 | 50.9 | 51.4 | 255.46 | 6300 | 25.4 | 124.80 | 2.05 | 646.64 | | | |
| 5 | 49.4 | 50.8 | 51.5 | 255.58 | 7000 | 27.3 | 129.24 | 1.98 | 747.25 | | | |
| Average | | | | | | 26.4 | | 2.03 | | | | |

Appendix (b) Data of hydrated cement at 7 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.1 | 51.0 | 51.8 | 281.83 | 7800 | 29.9 | 132.35 | 2.13 | 895.01 | 851.55 | 1065.33 | 14.62 |
| 2 | 52.1 | 51.4 | 50.8 | 285.00 | 8000 | 29.3 | 136.04 | 2.09 | 857.10 | | | |
| 3 | 50.8 | 51.6 | 51.8 | 285.64 | 7500 | 28.0 | 135.78 | 2.10 | 786.23 | | | |
| 4 | 50.7 | 51.1 | 52.1 | 284.18 | 8000 | 30.3 | 134.98 | 2.11 | 915.75 | | | |
| 5 | 51.0 | 51.4 | 50.8 | 285.34 | 7600 | 28.4 | 133.17 | 2.14 | 807.26 | | | |
| Average | | | | | | 29.2 | | 2.12 | | | | |

Appendix (c) Data of hydrated cement at 21 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.5 | 50.4 | 50.3 | 262.23 | 7800 | 30.0 | 128.02 | 2.05 | 901.98 | 942.61 | 1179.12 | 15.38 |
| 2 | 50.5 | 50.6 | 50.2 | 261.67 | 8100 | 31.1 | 128.28 | 2.04 | 965.03 | | | |
| 3 | 50.4 | 50.5 | 50.4 | 263.54 | 8300 | 32.0 | 128.28 | 2.05 | 1021.33 | | | |
| 4 | 50.3 | 50.5 | 50.4 | 261.09 | 8000 | 30.9 | 128.02 | 2.04 | 952.61 | | | |
| 5 | 50.6 | 50.4 | 50.3 | 262.42 | 7700 | 29.6 | 128.28 | 2.05 | 875.53 | | | |
| Average | | | | | | 30.7 | | 2.05 | | | | |

Appendix (d) Data of hydrated cement at 28 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.3 | 50.5 | 50.4 | 260.65 | 8200 | 31.6 | 128.02 | 2.04 | 1000.83 | 1024.66 | 1281.08 | 16.01 |
| 2 | 50.6 | 50.2 | 50.5 | 263.63 | 8400 | 32.4 | 128.28 | 2.06 | 1050.27 | | | |
| 3 | 50.7 | 50.3 | 50.2 | 262.80 | 8300 | 31.9 | 128.02 | 2.05 | 1017.32 | | | |
| 4 | 50.6 | 50.5 | 50.3 | 261.43 | 8200 | 31.4 | 128.53 | 2.03 | 989.00 | | | |
| 5 | 50.4 | 50.6 | 50.2 | 262.30 | 8500 | 32.7 | 128.02 | 2.05 | 1066.91 | | | |
| Average | | | | | | 32.0 | | 2.04 | | | | |

Appendix (e) Data of hydrated cement with Mahaphant rice husk ash 10 percentages at 3 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 49.6 | 50.6 | 51.8 | 250.50 | 4700 | 18.4 | 130.01 | 1.93 | 336.81 | 372.91 | 470.50 | 9.88 |
| 2 | 51.8 | 52.1 | 50.4 | 262.57 | 5700 | 20.7 | 136.02 | 1.93 | 428.42 | | | |
| 3 | 51.8 | 52.0 | 50.0 | 265.66 | 5000 | 18.2 | 134.68 | 1.97 | 330.92 | | | |
| 4 | 51.3 | 51.6 | 50.8 | 259.91 | 6000 | 22.2 | 134.47 | 1.93 | 493.42 | | | |
| 5 | 52.1 | 51.7 | 50.8 | 262.81 | 4700 | 17.1 | 136.83 | 1.92 | 292.41 | | | |
| Average | | | | | | 19.3 | | 1.94 | | | | |

Appendix (f) Data of hydrated cement with Mahaphant rice husk ash 10 percentages at 7 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.7 | 50.8 | 49.8 | 249.30 | 5300 | 20.2 | 128.26 | 1.94 | 406.69 | 583.43 | 745.64 | 12.74 |
| 2 | 50.7 | 50.5 | 50.0 | 250.20 | 5050 | 19.3 | 128.02 | 1.95 | 373.63 | | | |
| 3 | 51.8 | 52.1 | 50.8 | 262.77 | 7400 | 26.9 | 137.10 | 1.92 | 722.07 | | | |
| 4 | 52.4 | 52.3 | 50.9 | 268.90 | 7700 | 27.5 | 139.42 | 1.93 | 758.17 | | | |
| 5 | 51.3 | 51.9 | 51.3 | 259.14 | 7300 | 26.9 | 136.54 | 1.90 | 721.99 | | | |
| Average | | | | | | 24.2 | | 1.93 | | | | |

Appendix (g) Data of hydrated cement with Mahaphant rice husk ash 10 percentages at 21 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.7 | 50.0 | 50.4 | 251.40 | 6250 | 24.2 | 127.76 | 1.97 | 583.79 | 688.54 | 863.62 | 13.23 |
| 2 | 50.4 | 50.2 | 50.3 | 252.25 | 7100 | 27.5 | 127.26 | 1.98 | 756.31 | | | |
| 3 | 50.1 | 50.1 | 50.3 | 244.56 | 7100 | 27.7 | 126.25 | 1.94 | 768.45 | | | |
| 4 | 50.4 | 50.0 | 50.2 | 247.10 | 7000 | 27.2 | 126.50 | 1.95 | 741.05 | | | |
| 5 | 50.8 | 50.2 | 50.4 | 248.60 | 6400 | 24.6 | 128.53 | 1.93 | 604.89 | | | |
| Average | | | | | | 26.2 | | 1.95 | | | | |

Appendix (h) Data of hydrated cement with Mahaphant rice husk ash 10 percentages at 28 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.3 | 50.5 | 49.6 | 246.23 | 6500 | 25.1 | 125.99 | 1.95 | 628.87 | 752.00 | 942.19 | 13.79 |
| 2 | 50.2 | 50.2 | 50.2 | 252.60 | 6900 | 26.8 | 126.51 | 2.00 | 720.00 | | | |
| 3 | 50.4 | 50.1 | 50.7 | 252.77 | 7350 | 28.5 | 128.02 | 1.97 | 813.75 | | | |
| 4 | 51.0 | 49.7 | 50.6 | 249.56 | 7350 | 28.4 | 128.26 | 1.95 | 807.56 | | | |
| 5 | 51.2 | 50.8 | 49.6 | 252.79 | 7500 | 28.3 | 129.01 | 1.96 | 798.56 | | | |
| Average | | | | | | 27.4 | | 1.97 | | | | |

Appendix (i) Data of hydrated cement with Mahaphant rice husk ash 15 percentages at 3 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.7 | 50.4 | 51.9 | 252.58 | 4700 | 18.0 | 132.62 | 1.90 | 324.92 | 358.71 | 456.52 | 9.89 |
| 2 | 51.0 | 50.7 | 51.6 | 249.99 | 4100 | 15.5 | 133.42 | 1.87 | 241.47 | | | |
| 3 | 50.6 | 51.4 | 51.0 | 256.88 | 4600 | 17.3 | 132.64 | 1.94 | 300.43 | | | |
| 4 | 51.3 | 51.8 | 50.6 | 259.85 | 5900 | 21.8 | 134.46 | 1.93 | 473.44 | | | |
| 5 | 51.5 | 51.8 | 51.8 | 259.64 | 6000 | 22.0 | 138.19 | 1.88 | 485.83 | | | |
| Average | | | | | | 18.9 | | 1.91 | | | | |

Appendix (j) Data of hydrated cement with Mahaphant rice husk ash 15 percentages at 7 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 49.6 | 51.7 | 52.2 | 256.33 | 7000 | 26.8 | 133.86 | 1.91 | 715.66 | 640.21 | 802.84 | 12.75 |
| 2 | 51.0 | 51.7 | 52.3 | 260.42 | 6500 | 24.2 | 137.90 | 1.89 | 583.66 | | | |
| 3 | 50.8 | 51.9 | 52.0 | 265.06 | 6700 | 24.9 | 137.10 | 1.93 | 620.21 | | | |
| 4 | 50.3 | 51.6 | 52.3 | 261.93 | 7200 | 27.2 | 135.74 | 1.93 | 739.06 | | | |
| 5 | 52.4 | 52.5 | 50.5 | 265.72 | 6600 | 23.5 | 138.93 | 1.91 | 552.79 | | | |
| Average | | | | | | 25.3 | | 1.92 | | | | |

Appendix (k) Data of hydrated cement with Mahaphant rice husk ash 15 percentages at 21 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 49.6 | 51.7 | 52.2 | 256.33 | 7100 | 27.1 | 133.86 | 1.91 | 736.25 | 666.54 | 834.57 | 12.75 |
| 2 | 51.0 | 51.7 | 52.3 | 260.42 | 6900 | 25.6 | 137.90 | 1.89 | 657.70 | | | |
| 3 | 50.8 | 51.9 | 52.0 | 265.06 | 6800 | 25.3 | 137.10 | 1.93 | 638.86 | | | |
| 4 | 50.3 | 51.6 | 52.3 | 261.93 | 7100 | 26.8 | 135.74 | 1.93 | 718.68 | | | |
| 5 | 52.4 | 52.5 | 50.5 | 265.72 | 6800 | 24.2 | 138.93 | 1.91 | 586.80 | | | |
| Average | | | | | | 25.8 | | 1.92 | | | | |

Appendix (l) Data of hydrated cement with Mahaphant rice husk ash 15 percentages at 28 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 51.5 | 50.6 | 50.1 | 247.30 | 7000 | 26.3 | 130.56 | 1.89 | 693.00 | 705.63 | 883.61 | 13.34 |
| 2 | 52.1 | 51.1 | 49.6 | 248.24 | 7300 | 26.9 | 132.05 | 1.8 | 722.07 | | | |
| 3 | 50.9 | 49.9 | 50.9 | 244.25 | 7400 | 28.6 | 129.28 | 1.89 | 815.23 | | | |
| 4 | 51.9 | 50.7 | 49.8 | 246.78 | 6800 | 25.3 | 131.40 | 1.88 | 641.39 | | | |
| 5 | 50.6 | 48.9 | 50.8 | 237.17 | 6500 | 25.7 | 125.70 | 1.89 | 662.77 | | | |
| Average | | | | | | 26.6 | | 1.89 | | | | |

Appendix (m) Data of hydrated cement with Mahaphant rice husk ash 20 percentages at 3 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.8 | 50.2 | 50.5 | 228.05 | 4650 | 17.9 | 128.78 | 1.77 | 319.32 | 338.14 | 425.73 | 9.36 |
| 2 | 50.5 | 50.0 | 50.3 | 224.12 | 4550 | 17.7 | 127.01 | 1.76 | 311.85 | | | |
| 3 | 51.9 | 50.9 | 52.3 | 262.37 | 5200 | 19.3 | 138.16 | 1.90 | 372.12 | | | |
| 4 | 52.3 | 52.1 | 50.5 | 261.16 | 5800 | 20.9 | 137.60 | 1.90 | 435.14 | | | |
| 5 | 52.9 | 52.4 | 50.5 | 259.56 | 4600 | 16.3 | 139.98 | 1.85 | 264.48 | | | |
| Average | | | | | | 18.4 | | 1.84 | | | | |

Appendix (n) Data of hydrated cement with Mahaphant rice husk ash 20 percentages at 7 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 52.3 | 52.2 | 50.8 | 263.46 | 6100 | 21.9 | 138.69 | 1.90 | 479.48 | 436.97 | 546.61 | 10.47 |
| 2 | 50.5 | 51.5 | 51.2 | 256.24 | 5400 | 20.3 | 133.16 | 1.92 | 414.04 | | | |
| 3 | 50.5 | 52.0 | 50.5 | 261.42 | 5500 | 20.5 | 132.61 | 1.97 | 421.30 | | | |
| 4 | 50.6 | 51.7 | 50.9 | 259.67 | 5500 | 20.6 | 133.16 | 1.95 | 424.52 | | | |
| 5 | 50.9 | 51.9 | 51.1 | 260.31 | 5700 | 21.1 | 134.99 | 1.93 | 447.13 | | | |
| Average | | | | | | 20.9 | | 1.93 | | | | |

Appendix (o) Data of hydrated cement at with Mahaphant rice husk ash 20 percentages 21 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 52.1 | 50.5 | 51.9 | 260.90 | 7400 | 27.6 | 136.55 | 1.91 | 759.73 | 600.84 | 761.84 | 12.69 |
| 2 | 50.1 | 51.6 | 51.2 | 258.70 | 7000 | 26.5 | 132.36 | 1.95 | 704.16 | | | |
| 3 | 51.2 | 51.1 | 50.8 | 260.90 | 6600 | 24.7 | 132.91 | 1.96 | 611.16 | | | |
| 4 | 51.3 | 51.1 | 51.9 | 265.63 | 5100 | 19.1 | 136.05 | 1.95 | 363.51 | | | |
| 5 | 51.1 | 51.3 | 51.9 | 261.84 | 6600 | 24.7 | 136.05 | 1.92 | 608.78 | | | |
| Average | | | | | | 24.5 | | 1.94 | | | | |

Appendix (p) Data of hydrated cement with Mahaphant rice husk ash 20 percentages at 28 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.6 | 50.5 | 50.2 | 242.90 | 6900 | 26.5 | 128.28 | 1.89 | 700.27 | 753.07 | 942.16 | 13.75 |
| 2 | 50.8 | 50.3 | 50.2 | 243.92 | 7400 | 28.4 | 128.27 | 1.90 | 805.48 | | | |
| 3 | 51.8 | 52.0 | 50.7 | 272.27 | 7500 | 27.3 | 136.57 | 1.99 | 744.58 | | | |
| 4 | 50.7 | 50.4 | 52.6 | 265.37 | 7400 | 28.4 | 134.41 | 1.97 | 805.45 | | | |
| 5 | 51.3 | 50.8 | 52.4 | 264.53 | 7100 | 26.7 | 136.56 | 1.94 | 412.86 | | | |
| Average | | | | | | 27.4 | | 1.94 | | | | |

Appendix (q) Data of hydrated cement with Mahaphant rice husk ash 25 percentages at 3 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 51.9 | 51.8 | 51.2 | 252.35 | 4600 | 16.8 | 137.65 | 1.83 | 281.17 | 185.51 | 237.13 | 7.18 |
| 2 | 52.3 | 51.2 | 51.8 | 251.47 | 4000 | 14.6 | 138.71 | 1.81 | 214.30 | | | |
| 3 | 50.5 | 52.0 | 51.1 | 244.17 | 3350 | 12.5 | 134.19 | 1.82 | 156.30 | | | |
| 4 | 49.8 | 50.9 | 52.0 | 247.28 | 3500 | 13.5 | 131.81 | 1.88 | 183.10 | | | |
| 5 | 49.6 | 51.9 | 49.5 | 233.30 | 2800 | 10.7 | 127.42 | 1.83 | 113.62 | | | |
| Average | | | | | | 13.6 | | 1.83 | | | | |

Appendix (r) Data of hydrated cement with Mahaphant rice husk ash 25 percentages at 7 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 49.9 | 52.1 | 50.8 | 243.07 | 4250 | 16.0 | 132.07 | 1.84 | 256.66 | 263.00 | 339.03 | 8.72 |
| 2 | 51.8 | 51.0 | 51.8 | 250.98 | 4000 | 14.8 | 136.85 | 1.83 | 220.18 | | | |
| 3 | 49.2 | 52.5 | 50.5 | 241.08 | 5700 | 21.6 | 130.44 | 1.85 | 467.68 | | | |
| 4 | 51.3 | 50.8 | 52.0 | 246.98 | 3500 | 13.2 | 135.51 | 1.82 | 173.23 | | | |
| 5 | 49.3 | 51.5 | 51.5 | 243.66 | 4000 | 15.4 | 130.76 | 1.86 | 238.38 | | | |
| Average | | | | | | 16.2 | | 1.84 | | | | |

Appendix (s) Data of hydrated cement with Mahaphant rice husk ash 25 percentages at 21 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.9 | 50.9 | 52.3 | 247.18 | 4300 | 16.3 | 135.50 | 1.82 | 264.56 | 315.53 | 403.88 | 9.40 |
| 2 | 46.5 | 50.5 | 52.2 | 242.63 | 5400 | 22.5 | 122.58 | 1.98 | 507.87 | | | |
| 3 | 49.8 | 52.2 | 50.9 | 248.64 | 3900 | 14.7 | 132.32 | 1.88 | 216.16 | | | |
| 4 | 47.8 | 50.8 | 52.2 | 245.30 | 4700 | 19.0 | 126.75 | 1.94 | 359.80 | | | |
| 5 | 49.3 | 52.3 | 51.0 | 245.34 | 4300 | 16.3 | 131.50 | 1.87 | 267.11 | | | |
| Average | | | | | | 17.8 | | 1.90 | | | | |

Appendix (t) Data of hydrated cement with Mahaphant rice husk ash 25 percentages at 28 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 47.8 | 52.0 | 50.6 | 252.02 | 4900 | 19.3 | 125.77 | 2.00 | 373.23 | 332.64 | 416.73 | 9.17 |
| 2 | 50.1 | 51.0 | 51.9 | 251.67 | 5000 | 19.2 | 132.61 | 1.90 | 367.77 | | | |
| 3 | 50.4 | 52.2 | 50.4 | 245.22 | 4600 | 17.1 | 132.60 | 1.85 | 293.61 | | | |
| 4 | 50.3 | 52.4 | 50.4 | 248.93 | 4800 | 17.8 | 132.84 | 1.87 | 318.52 | | | |
| 5 | 49.9 | 52.3 | 52.3 | 240.94 | 4600 | 17.7 | 133.10 | 1.81 | 313.78 | | | |
| Average | | | | | | 18.2 | | 1.89 | | | | |

Appendix (u) Data of hydrated cement with A.T. Bio Power rice husk ash 10 percentages at 3 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 51.4 | 50.3 | 50.0 | 257.70 | 6000 | 22.7 | 129.27 | 1.99 | 517.24 | 549.66 | 687.60 | 11.74 |
| 2 | 51.4 | 50.4 | 50.2 | 257.00 | 6100 | 23.1 | 130.05 | 1.98 | 532.51 | | | |
| 3 | 51.6 | 50.4 | 50.0 | 256.55 | 6500 | 24.5 | 130.03 | 1.97 | 599.95 | | | |
| 4 | 51.5 | 50.4 | 50.1 | 256.87 | 6100 | 23.0 | 130.04 | 1.98 | 530.44 | | | |
| 5 | 51.4 | 50.3 | 50.0 | 257.3 | 6300 | 23.9 | 129.27 | 1.99 | 570.26 | | | |
| Average | | | | | | 23.4 | | 1.98 | | | | |

Appendix (v) Data of hydrated cement with A.T. Bio Power rice husk ash 10 percentages at 7 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 52.4 | 50.8 | 50.5 | 274.93 | 9900 | 36.4 | 134.43 | 2.05 | 1328.41 | 1331.14 | 1665.76 | 18.29 |
| 2 | 50.5 | 51.1 | 51.8 | 274.28 | 9420 | 35.8 | 133.67 | 2.05 | 1279.76 | | | |
| 3 | 52.5 | 50.4 | 50.4 | 275.52 | 9500 | 35.2 | 133.36 | 2.07 | 1238.00 | | | |
| 4 | 51.6 | 50.5 | 52.3 | 287.52 | 10300 | 38.7 | 136.28 | 2.11 | 1500.53 | | | |
| 5 | 51.5 | 51.4 | 50.8 | 280.15 | 9800 | 36.3 | 134.47 | 2.08 | 1316.33 | | | |
| Average | | | | | | 36.5 | | 2.07 | | | | |

Appendix (w) Data of hydrated cement with A.T. Bio Power rice husk ash 10 percentages at 21 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 51.8 | 50.5 | 51.2 | 263.25 | 8100 | 30.3 | 133.93 | 1.97 | 920.83 | 887.35 | 1110.12 | 14.93 |
| 2 | 52.1 | 51.4 | 51.2 | 264.31 | 7700 | 28.2 | 137.11 | 1.93 | 794.02 | | | |
| 3 | 50.8 | 51.1 | 50.8 | 263.43 | 8000 | 30.2 | 131.87 | 2.00 | 912.14 | | | |
| 4 | 50.5 | 51.1 | 51.2 | 262.61 | 7800 | 29.6 | 132.12 | 1.99 | 877.44 | | | |
| 5 | 51.3 | 51.2 | 50.9 | 261.70 | 8200 | 30.6 | 133.69 | 1.96 | 936.66 | | | |
| Average | | | | | | 29.8 | | 1.97 | | | | |

Appendix (x) Data of hydrated cement with A.T. Bio Power rice husk ash 10 percentages at 28 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 51.3 | 50.0 | 50.4 | 258.09 | 9100 | 34.8 | 129.28 | 2.00 | 1208.82 | 1184.75 | 1481.84 | 17.24 |
| 2 | 51.5 | 50.3 | 50.7 | 260.61 | 8700 | 32.9 | 131.34 | 1.98 | 1083.28 | | | |
| 3 | 52.1 | 50.4 | 50.1 | 262.77 | 9500 | 35.5 | 131.55 | 2.00 | 1257.08 | | | |
| 4 | 51.4 | 51.8 | 50.9 | 261.40 | 9300 | 34.2 | 135.52 | 1.93 | 1171.74 | | | |
| 5 | 51.8 | 51.5 | 51.5 | 263.43 | 9400 | 34.7 | 136.59 | 1.93 | 1206.45 | | | |
| Average | | | | | | | | 1.97 | | | | |

Appendix (y) Data of hydrated cement with A.T. Bio Power rice husk ash 15 percentages at 3 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.8 | 51.5 | 52.4 | 269.35 | 8000 | 30.0 | 137.09 | 1.96 | 898.03 | 931.42 | 728.47 | 12.09 |
| 2 | 51.4 | 50.5 | 52.0 | 270.85 | 8400 | 31.7 | 134.98 | 2.01 | 1005.78 | | | |
| 3 | 51.8 | 51.3 | 50.6 | 270.45 | 9200 | 33.9 | 134.46 | 2.01 | 1151.15 | | | |
| 4 | 51.9 | 51.3 | 51.4 | 272.18 | 7200 | 26.5 | 136.85 | 1.99 | 702.34 | | | |
| 5 | 51.7 | 51.3 | 50.7 | 271.09 | 8250 | 30.5 | 134.47 | 2.02 | 929.28 | | | |
| Average | | | | | | 30.5 | | 1.99 | | | | |

Appendix (z) Data of hydrated cement with A.T. Bio Power rice husk ash 15 percentages at 7 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 51.0 | 52.1 | 50.4 | 258.61 | 6500 | 24.0 | 133.92 | 1.93 | 574.73 | 582.36 | 1171.64 | 15.50 |
| 2 | 50.8 | 51.9 | 50.7 | 262.64 | 6800 | 25.3 | 133.67 | 1.96 | 638.86 | | | |
| 3 | 50.3 | 52.1 | 50.9 | 261.20 | 6300 | 23.6 | 133.39 | 1.96 | 555.04 | | | |
| 4 | 51.1 | 52.0 | 50.7 | 261.30 | 6600 | 24.3 | 134.72 | 1.94 | 592.50 | | | |
| 5 | 51.6 | 51.7 | 51.4 | 267.60 | 6400 | 23.5 | 137.12 | 1.95 | 552.75 | | | |
| Average | | | | | | 24.1 | | 1.95 | | | | |

Appendix (aa) Data of hydrated cement with A.T. Bio Power rice husk ash 15 percentages at 21 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.5 | 49.6 | 50.7 | 254.27 | 7150 | 28.0 | 126.99 | 2.00 | 782.56 | 940.04 | 1183.17 | 15.59 |
| 2 | 50.0 | 50.7 | 49.5 | 252.94 | 7200 | 27.8 | 125.48 | 2.02 | 774.75 | | | |
| 3 | 50.5 | 50.1 | 50.1 | 257.07 | 8950 | 34.7 | 126.76 | 2.03 | 1201.82 | | | |
| 4 | 50.5 | 50.2 | 50.2 | 258.31 | 8200 | 31.6 | 127.52 | 2.03 | 1000.83 | | | |
| 5 | 50.5 | 50.0 | 50.0 | 255.62 | 8100 | 31.2 | 127.26 | 2.01 | 972.70 | | | |
| Average | | | | | | 30.7 | | 2.02 | | | | |

Appendix (ab) Data of hydrated cement with A.T. Bio Power rice husk ash 15 percentages at 28 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.4 | 50.4 | 50.2 | 260.00 | 10300 | 39.7 | 127.52 | 2.04 | 1579.08 | 1348.42 | 1689.09 | 18.46 |
| 2 | 51.1 | 50.3 | 50.2 | 258.80 | 9400 | 35.8 | 129.03 | 2.01 | 1284.49 | | | |
| 3 | 50.6 | 50.3 | 50.1 | 258.60 | 9000 | 34.7 | 127.51 | 2.03 | 1200.88 | | | |
| 4 | 50.7 | 50.4 | 50.2 | 260.35 | 9500 | 36.4 | 128.28 | 2.03 | 1327.46 | | | |
| 5 | 51.0 | 50.2 | 50.2 | 259.00 | 9650 | 36.9 | 128.52 | 2.02 | 1364.45 | | | |
| Average | | | | | | 36.7 | | 2.02 | | | | |

Appendix (ac) Data of hydrated cement with AT Bio Power rice husk ash 20 percentages at 3 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.7 | 50.6 | 51.9 | 262.45 | 7300 | 27.9 | 133.15 | 1.97 | 777.64 | 704.05 | 883.37 | 13.39 |
| 2 | 51.7 | 51.3 | 51.2 | 261.64 | 6500 | 24.0 | 135.79 | 1.93 | 576.85 | | | |
| 3 | 52.3 | 50.1 | 50.3 | 256.86 | 6800 | 25.4 | 131.80 | 1.95 | 646.83 | | | |
| 4 | 50.8 | 51.5 | 51.1 | 257.62 | 7600 | 28.5 | 133.69 | 1.93 | 810.47 | | | |
| 5 | 51.2 | 51.3 | 51.1 | 258.98 | 7200 | 26.9 | 134.22 | 1.93 | 721.68 | | | |
| Average | | | | | | 26.5 | | 1.94 | | | | |

Appendix (ad) Data of hydrated cement with A.T. Bio Power rice husk ash 20 percentages at 7 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.2 | 51.1 | 51.1 | 251.95 | 6600 | 25.0 | 132.11 | 1.91 | 625.92 | 911.96 | 1151.81 | 15.49 |
| 2 | 43.9 | 44.0 | 50.9 | 257.26 | 6800 | 34.5 | 99.32 | 2.62 | 1190.24 | | | |
| 3 | 50.3 | 51.8 | 51.1 | 257.92 | 8400 | 31.6 | 133.14 | 1.94 | 998.19 | | | |
| 4 | 50.9 | 50.4 | 51.7 | 253.12 | 7800 | 29.8 | 132.63 | 1.91 | 887.86 | | | |
| 5 | 50.9 | 51.2 | 51.7 | 256.80 | 8000 | 30.1 | 134.73 | 1.91 | 905.02 | | | |
| Average | | | | | | 30.2 | | 2.06 | | | | |

Appendix (ae) Data of hydrated cement with A.T. Bio Power rice husk ash 20 percentages at 21 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.7 | 50.9 | 49.6 | 254.52 | 8700 | 33.0 | 128.00 | 1.99 | 1091.54 | 1120.89 | 1403.01 | 16.80 |
| 2 | 50.6 | 50.6 | 49.8 | 256.58 | 9300 | 35.6 | 127.51 | 2.01 | 1267.12 | | | |
| 3 | 50.8 | 50.5 | 50.1 | 258.47 | 8350 | 31.9 | 128.53 | 2.01 | 1017.45 | | | |
| 4 | 50.5 | 50.6 | 50.1 | 257.32 | 8600 | 33.0 | 128.02 | 2.01 | 1087.84 | | | |
| 5 | 50.4 | 50.5 | 50.0 | 257.98 | 8800 | 33.9 | 127.26 | 2.03 | 1148.08 | | | |
| Average | | | | | | 33.5 | | 2.01 | | | | |

Appendix (af) Data of hydrated cement with A.T. Bio Power rice husk ash 20 percentages at 28 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2/n-1$ | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.6 | 50.7 | 50.2 | 257.80 | 10800 | 41.3 | 128.78 | 2.00 | 1702.09 | 1583.21 | 1980.54 | 19.93 |
| 2 | 50.5 | 50.3 | 50.2 | 256.35 | 10500 | 40.5 | 127.52 | 2.01 | 1641.01 | | | |
| 3 | 50.5 | 50.4 | 50.1 | 256.15 | 9900 | 38.1 | 127.51 | 2.01 | 1453.04 | | | |
| 4 | 50.1 | 50.1 | 50.5 | 251.20 | 10000 | 39.0 | 126.76 | 1.98 | 1524.41 | | | |
| 5 | 50.2 | 50.0 | 50.2 | 250.57 | 10250 | 40.0 | 126.02 | 1.98 | 1601.59 | | | |
| Average | | | | | | 39.8 | | 2.00 | | | | |

Appendix (ag) Data of hydrated cement with A.T. Bio Power rice husk ash 25 percentages at 3 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.8 | 52.3 | 52.1 | 259.15 | 7000 | 25.8 | 138.42 | 1.87 | 666.68 | 724.81 | 911.74 | 13.67 |
| 2 | 52.3 | 52.1 | 50.4 | 263.20 | 7800 | 28.1 | 137.33 | 1.92 | 786.98 | | | |
| 3 | 52.3 | 53.0 | 51.0 | 263.33 | 6700 | 23.7 | 141.37 | 1.86 | 561.11 | | | |
| 4 | 50.8 | 52.6 | 52.5 | 266.40 | 8200 | 30.1 | 140.28 | 1.90 | 904.44 | | | |
| 5 | 50.9 | 52.1 | 51.3 | 265.40 | 7300 | 27.0 | 136.04 | 1.95 | 727.76 | | | |
| Average | | | | | | 26.9 | | 1.90 | | | | |

Appendix (ah) Data of hydrated cement with A.T. Bio Power rice husk ash 25 percentages at 7 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.8 | 51.3 | 52.1 | 260.73 | 8600 | 32.3 | 135.77 | 1.92 | 1045.89 | 936.76 | 1172.67 | 15.36 |
| 2 | 51.4 | 50.6 | 52.5 | 261.20 | 8400 | 31.7 | 136.54 | 1.91 | 1001.81 | | | |
| 3 | 51.0 | 51.1 | 52.6 | 261.73 | 7800 | 29.3 | 137.08 | 1.90 | 860.32 | | | |
| 4 | 51.1 | 52.1 | 51.1 | 262.48 | 8100 | 29.8 | 136.04 | 1.93 | 889.01 | | | |
| 5 | 49.9 | 51.9 | 50.7 | 258.81 | 7900 | 29.9 | 131.30 | 1.97 | 893.66 | | | |
| Average | | | | | | 30.6 | | 1.93 | | | | |

Appendix (ai) Data of hydrated cement with A.T. Bio Power rice husk ash 25 percentages at 21 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.4 | 49.8 | 50.2 | 245.58 | 7200 | 28.1 | 126.00 | 1.95 | 790.31 | 788.53 | 986.06 | 14.05 |
| 2 | 51.0 | 50.2 | 50.4 | 248.92 | 7100 | 27.2 | 129.03 | 1.93 | 738.62 | | | |
| 3 | 50.3 | 49.9 | 49.9 | 246.10 | 7400 | 28.9 | 125.25 | 1.96 | 834.79 | | | |
| 4 | 50.5 | 50.0 | 50.1 | 246.38 | 7300 | 28.3 | 126.50 | 1.95 | 802.74 | | | |
| 5 | 50.4 | 50.2 | 50.1 | 247.03 | 7200 | 27.9 | 126.76 | 1.95 | 777.77 | | | |
| Average | | | | | | 28.1 | | 1.95 | | | | |

Appendix (aj) Data of hydrated cement with A.T. Bio Power rice husk ash 25 percentages at 28 days

| Specimen | Width (mm) | Length (mm) | Height (mm) | Weight (g) | Force (kg) | Strength (MPa) | Bulk Volume ($cm^3$) | Bulk Density ($g/cm^3$) | $x_i^2$ | $\mu^2$ | Summation $x_i^2$/n-1 | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.6 | 49.4 | 50.7 | 245.52 | 8400 | 32.9 | 126.73 | 1.94 | 1084.57 | 1096.22 | 1379.15 | 16.82 |
| 2 | 49.1 | 50.3 | 49.9 | 242.52 | 7300 | 29.0 | 123.24 | 1.97 | 839.07 | | | |
| 3 | 49.8 | 50.6 | 49.5 | 244.20 | 9600 | 37.3 | 124.73 | 1.96 | 1393.91 | | | |
| 4 | 50.2 | 49.9 | 50.3 | 243.87 | 8600 | 33.6 | 126.00 | 1.94 | 1131.99 | | | |
| 5 | 50.3 | 50.1 | 50.4 | 244.25 | 8400 | 32.7 | 127.01 | 1.92 | 1067.09 | | | |
| Average | | | | | | 33.1 | | 1.94 | | | | |

Appendix (ak) ASTM C188-95

Designation: C 188 – 95 (Reapproved 2003)

American Association State Highway and Transportation Officials Standard
AASHTO No.: T133

# Standard Test Method for Density of Hydraulic Cement[1]

This standard is issued under the fixed designation C 188; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense.*

## 1. Scope

1.1 This test method covers the determination of the density of hydraulic cement. Its particular usefulness is in connection with the design and control of concrete mixtures.

1.2 The density of hydraulic cement is defined as the mass of a unit volume of the solids.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

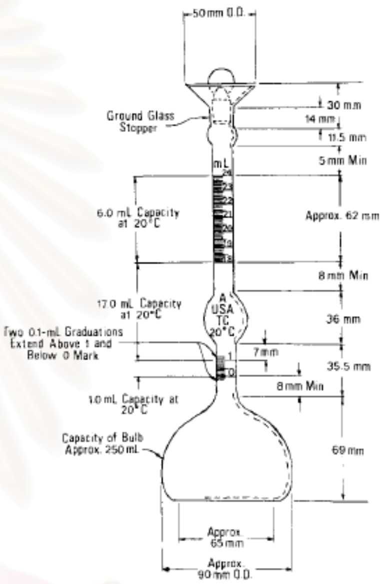
C 114 Test Methods for Chemical Analysis of Hydraulic Cement[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[3]

## 3. Apparatus

3.1 *Le Chatelier flask*—The standard flask, which is circular in cross section, with shape and dimensions conforming essentially to Fig. 1 (Note 1). The requirements in regard to tolerance, inscription and length, spacing, and uniformity of graduation will be rigidly observed. There shall be a space of at least 10 mm between the highest graduation mark and the lowest point of grinding for the glass stopper.

3.1.1 The material of construction shall be excellent quality glass, transparent and free of striae. The glass shall be chemically resistant and shall have small thermal hysteresis. The flasks shall be thoroughly annealed before being graduated. They shall be of sufficient thickness to ensure reasonable resistance to breakage.




NOTE—Variations of a few millimetres in such dimensions as total height of flask, diameter of base, and so forth, are to be expected and will not be considered sufficient cause for rejection. The dimensions of the flask shown in Fig. 1 apply only to new flasks and not to flasks in use which meet the other requirements of this test method.

**FIG. 1 Le Chatelier Flask for Density Test**

3.1.2 The neck shall be graduated from 0 to 1 mL and from 18 to 24 mL in 0.1-mL graduations. The error of any indicated capacity shall not be greater than 0.05 mL.

3.1.3 Each flask shall bear a permanent identification number and the stopper, if not interchangeably ground, shall bear the same number. Interchangeable ground-glass parts shall be marked on both members with the standard-taper symbol, followed by the size designation. The standard temperature shall be indicated, and the unit of capacity shall be shown by the letters "mL" placed above the highest graduation mark.

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[1] This test method is under the jurisdiction of ASTM Committee C01 on Cement, and is the direct responsibility of Subcommittee C01.25 on Fineness.

Current edition approved June 10, 2003. Published August 2003. Originally approved in 1944. Last previous edition approved in 1995 as C 188 – 95.

[2] *Annual Book of ASTM Standards*, Vol 04.01.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

3.2 Kerosine, free of water, or naphtha, having a density greater than 0.73 g/mL at 23 ± 2° C shall be used in the density determination.

3.3 The use of alternative equipment or methods for determining density is permitted provided that a single operator can obtain results within ± 0.03 $Mg/m^3$ of the results obtained using the flask method.

NOTE 1—The design is intended to ensure complete drainage of the flask when emptied, and stability of standing on a level surface, as well as accuracy and precision of reading.

## 4. Procedure

4.1 Determine the density of cement on the material as received, unless otherwise specified. If the density determination on a loss-free sample is required, first ignite the sample as described in the test for loss on ignition in section 16.1 on Portland Cement of Test Methods C 114.

4.2 Fill the flask (Note 2) with either of the liquids specified in 3.2 to a point on the stem between the 0 and the 1-mL mark. Dry the inside of the flask above the level of the liquid, if necessary, after pouring. Record the first reading after the flask has been immersed in the water bath (Note 3) in accordance with 4.4.

NOTE 2—It is advisable to use a rubber pad on the table top when filling or rolling the flask.

NOTE 3—Before the cement has been added to the flask, a loose-fitting, lead-ring weight around the stem of the flask will be helpful in holding the flask in an upright position in the water bath, or the flask may be held in the water bath by a buret clamp.

4.3 Introduce a quantity of cement, weighed to the nearest 0.05 g, (about 64 g for portland cement) in small increments at the same temperature as the liquid (Note 2). Take care to avoid splashing and see that the cement does not adhere to the inside of the flask above the liquid. A vibrating apparatus may be used to accelerate the introduction of the cement into the flask and to prevent the cement from sticking to the neck. After all the cement has been introduced, place the stopper in the flask and roll the flask in an inclined position (Note 2), or gently whirl it in a horizontal circle, so as to free the cement from air until no further air bubbles rise to the surface of the liquid. If a proper amount of cement has been added, the level of the liquid will be in its final position at some point of the upper series of graduations. Take the final reading after the flask has been immersed in the water bath in accordance with 4.4.

4.4 Immerse the flask in a constant-temperature water bath for sufficient periods of time in order to avoid flask temperature variations greater than 0.2°C between the initial and the final readings.

## 5. Calculation

5.1 The difference between the first and the final readings represents the volume of liquid displaced by the mass of cement used in the test.

5.2 Calculate the cement density, ρ, as follows:

$$\rho(Mg/m^3) = \rho(g/cm^3) = \text{mass of cement, g/displaced volume, cm}^3$$

NOTE 4—The displaced volume in millilitres is numerically equal to the displaced volume in cubic centimetres.

NOTE 5—Density in megagrams per cubic metre ($Mg/m^3$) is numerically equal to grams per cubic centimetre ($g/cm^3$). Calculate the cement density, ρ, to three decimal places and round to the nearest 0.01 $Mg/m^3$.

NOTE 6—In connection with proportioning and control of concrete mixtures, density may be more usefully expressed as specific gravity, the latter being a dimensionless number. Calculate the specific gravity as follows: Sp gr = cement density/water density at 4°C (at 4°C the density of water is 1 $Mg/m^3$(1$g/cm^3$)).

## 6. Precision and Bias

6.1 The single-operator standard deviation for portland cements has been found to be 0.012.[4] Therefore, the results of two properly conducted tests by the same operator on the same material should not differ by more than 0.03.

6.2 The multilaboratory standard deviation for portland cements has been found to be 0.037.[4] Therefore, the results of two properly conducted tests from two different laboratories on samples of the same cement should not differ by more than 0.10.[4]

6.3 Since there is no accepted reference material suitable for determining any bias that might be associated with this test method, no statement on bias is being made.

## 7. Keywords

7.1 density; hydraulic cement; specific gravity

[4] These numbers represent the 1s and d2s limits described in Practice C 670.

# BIOGRAPHY

Mr.Worrachead Somboonna was born on November 14, 1983 in Bangkok, Thailand. He attended Narkprasith School in Nakornpathom and graduated in 2000. He received his Bachelor's Degree in Materials science from Faculty of Science, Chulalongkorn University in 2004.