รายงานวิจัยฉบับสมบูรณ์

การพัฒนาส่วนผสมของกากแคลเซียมคาร์ไบด์และเถ้าถ่านหินเพื่อใช้ในงานคอนกรีต

โดย

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มิถุนายน 2559

สัญญาเลขที่ TRG5780073

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สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัย

Abstract

Project Code : TRG5780073

Project Title : Development of calcium carbide residue and fly ash mixtures in concrete work

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Project Period : 2 years (2 June 2014 – 1 June 2016**)**

This research aimed to develop of calcium carbide residue and fly ash mixtures in concrete. Calcium carbide residue was mixed with fly ash at a ratio of 30:70 by weight and used as a new cementing material to cast concrete. All concretes mixtures had the water to binder ratio of 0.25 and superplasticizer was employed in order to control slump of fresh concrete between 15 and 20 cm. There were three activation methods to promote strength development of a new cementing material which were (1) adding 1% of NaOH by weight of binder, (2) curing concrete at elevated temperature of 60 °C, and (3) increasing the fineness of calcium carbide residue and fly ash by grinding (the particles retained on a sieve No 325 were 1-3% by weight). All concretes were tested to determine the compressive strength and modulus of elasticity. Additionally, heat evolution, chloride resistance, and corrosion of embedded steel were also investigated

The results showed that all activation methods could improve strength of concrete made from calcium carbide residue and fly ash mixture, an increasing the fineness of a new cementing material was the most effective method as compared with other methods. The compressive strength of concrete activated with increasing the fineness of a new cementing material could be as high as 561 ksc at 28 days and increased up to 664 ksc at 90 days. Concrete made form calcium carbide residue and fly and mixture had elastic modulus similar to OPC concrete and all activation methods had no significant effects on elastic modulus of concrete. The peak temperature rise of concrete made from calcium carbide residue and fly ash could be reduced by 30 – 36 ^{O}C from the OPC concrete. Chloride resistance of concrete in term of chloride ion penetration and corrosion of embedded steel could be considerably improved by all strength activation methods.

Keywords : Calcium Carbide Residue / Fly Ash / Chloride Resistance

บทคัดย่อ

รหัสโครงการ : TRG5780073

ชื่อโครงการ : การพัฒนาส่วนผสมของกากแคลเซียมคาร์ไบด์และเถ้าถ่านหินเพื่อใช้ในงานคอนกรีต

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งานวิจัยนี้มีวัตถุประสงค์เพื่อพัฒนาส่วนผสมของกากแคลเซียมคาร์ไบด์และเถ้าถ่านหินเพื่อใช้ในงานคอนกรีต ใช้อัตราส่วนกากแคลเซียมคาร์ไบด์ต่อเถ้าถ่านหินเท่ากับ 30 : 70 โดยน้ำหนัก เพื่อใช้เป็นวัสดุประสานชนิดใหม่ในการผลิตคอนกรีต มีอัตราส่วนน้ำต่อวัสดุประสานเท่ากับ 0.25 และใช้สารลดน้ำพิเศษควบคุมค่าการยุบตัวของคอนกรีตให้มีค่าระหว่าง 15 - 20 ซม. ทำการกระตุ้นกำลัง 3 วิธี ซึ่งได้แก่ เติมสารโซเดียมไฮดรอกไซด์ (NaOH) ร้อยละ 1 โดยน้ำหนักวัสดุประสาน, บ่มด้วยความร้อนที่อุณหภูมิ 60 องศาเซลเซียส และเพิ่มความละเอียดของวัสดุประสาน (มีปริมาณอนุภาคค้างบนตะแกรงเบอร์ 325 ร้อยละ 1-3) ทดสอบกำลังอัดและโมดูลัสยืดหยุ่น และความทนทานของคอนกรีต ได้แก่ ความร้อนที่เกิดขึ้นในคอนกรีต ความต้านทานคลอไรด์ และการกัดกร่อนของเหล็กเสริมในคอนกรีต

ผลการทดสอบพบว่าวิธีการกระตุ้นกำลังทั้ง 3 วิธี สามารถเพิ่มกำลังอัดของคอนกรีตได้ดีขึ้น โดยวิธีการเพิ่มความละเอียดของวัสดุประสานเป็นวิธีที่มีประสิทธิภาพมากที่สุด ซึ่งสามารถพัฒนากำลังคอนกรีตได้สูงถึง 561 กก/ซม2 ที่อายุ 28 วัน และ 644 กก/ซม2 ที่อายุ 90 วัน คอนกรีตที่ใช้กากแคลเซียมคาร์ไบด์และเถ้าถ่านหินเป็นวัสดุประสานมีค่าโมดูลัสยืดหยุ่นของคอนกรีตทิศทางเดียวกับคอนกรีตที่ใช้ปูนซีเมนต์ และการกระตุ้นกำลังของคอนกรีตด้วยวิธีต่าง ๆ ไม่ส่งผลกระทบต่อค่าโมดูลัสยืดหยุ่นของคอนกรีต อุณหภูมิที่เพิ่มขึ้นสูงสุดในคอนกรีตที่ทำจากกากแคลเซียมคาร์ไบด์และเถ้าถ่านหินมีค่าลดลง 30-36 องศาเซลเซียส เมื่อเทียบกับคอนกรีตที่ใช้ปูนซีเมนต์ ความสามารถต้านทานคลอไรด์ของคอนกรีต พบว่าวิธีการกระตุ้นกำลังทั้ง 3 วิธี สามารถลดการแทรกซึมของคลอไรด์อิออนและการกัดกร่อนของเหล็กที่ฝังในคอนกรีตได้

คำหลัก : กากแคลเซียมคาร์ไบด์ / เถ้าถ่านหิน / ความต้านทานคลอไรด์ /

Executive Summary

This research aimed to develop of calcium carbide residue and fly ash mixtures in concrete. Calcium carbide residue was mixed with fly ash at a ratio of 30:70 by weight and used as a new cementing material to cast concrete and concrete block. All concretes mixtures had the water to binder ratio of 0.25 and superplasticizer was employed in order to control slump of fresh concrete between 15 and 20 cm. There were three activation methods to promote strength development of a new cementing material which were (1) adding 1% of NaOH by weight of binder, (2) curing concrete at elevated temperature of 60 °C, and (3) increasing the fineness of calcium carbide residue and fly ash by grinding (the particles retained on a sieve No 325 were 1-3% by weight). All concretes were tested to determine the compressive strength and modulus of elasticity. Additionally, heat evolution, chloride resistance, and corrosion of embedded steel were also investigated.

For concrete block, it was prepared with binder (CCR and fly ash mixture), water, and recycled fine aggregate. The concrete block specimen having a cross section of 10 x 10 cm^2 and a length of 20 cm was used in this study. All concrete block mixtures was cast by using the pressure of 6 and 8 MPa. The binder to aggregate ratio was 1:3 by weight and water to binder ratio was varied as 0.30, 0.35, and 0.40. The compressive strength and water absorption of concrete block were investigated.

The results showed that all activation methods could improve strength of concrete made from calcium carbide residue and fly ash mixture, an increasing the fineness of a new cementing material was the most effective method as compared with other methods. The compressive strength of concrete activated with increasing the fineness of a new cementing material could be as high as 561 ksc at 28 days and increased up to 664 ksc at 90 days. Concrete made form calcium carbide residue and fly and mixture had elastic modulus similar to OPC concrete and all activation methods had no significant effects on elastic modulus of concrete. The peak temperature rise of concrete made from calcium carbide residue and fly ash could be reduced by 30 – 36 ^{O}C from the OPC concrete. Chloride resistance of concrete in term of chloride ion penetration and corrosion of embedded steel could be considerably improved by all strength activation methods.

For concrete block, it was found that the absorption of water decreased with the increase of density of concrete block, which were approximately 7 to 13% by weight. The compressive strength of concrete block made from the waste materials was 41.4 MPa at 28 days and developed as high as 45.3 MPa at 60 days. The results also suggested that the waste materials, calcium carbide residue, fly ash, and recycled fine aggregate could be used as raw materials to make concrete block without Portland cement and the block is met the requirement specified by TIS 827 standard and ASTM C1319 from which the compressive strength of the block is higher than 40 MPa and 31 MPa respectively.

DEVELOPMENT OF CALCIUM CARBIDE RESIDUE AND FLY ASH MIXTURES IN CONCRETE WORK

1. Introduction

Concrete is one of the most widely used construction materials in the world and Portland cement is a primary concrete binder. In Thailand, recent statistics have shown that more than 28 million tons of Portland cement (The office of industrial economics, 2012) is produced from the cement manufacture each year; this value is showing a rapidly increasing trend due to industry expansion and economic growth. It is well known that the production process for Portland cement requires large amounts of energy to burn the raw material at temperatures of up to 1,500 degree Celsius. Moreover, the production of 1 ton of Portland cement releases as much as 900 kg of CO_2 into the atmosphere (Mehta, 2009). As a result, Portland cement contributes to environmental problems such as dust pollution and thinning of the ozone layer, which contributes to global warming. To reduce CO_2 emissions, cement manufacturers have attempted to reduce Portland cement consumption through the use of supplementary cementitious materials, such as fly ash and natural pozzolans, to partially replace Portland cement in concrete (Shannag, 2000; Hassan et al., 2000; Poon et al., 2000). However, Portland cement is still the main cementitious material in concrete.

Calcium carbide residue (CCR), a by-product of acetylene gas production through the hydrolysis of calcium carbide (CaC_2) as shown in equation (1), is mainly composed of calcium hydroxide ($Ca(OH)_2$) in a slurry form. In Thailand, more than 21,500 tons per year of CCR has been produced, and this figure trends to increase annually because acetylene gas is a major gas for welding, metal cutting, and to ripen fruit. The utilization of CCR is minimal compared to the quantity produced, some applications of CCR is sewage and water treatment (Cardoso et al., 2009). Most CCR is disposed of as waste in landfills and there is currently no good method to eliminate it from the ecosystem, resulting in various environmental problems, particularly in case of ground water pollution due to high alkalinity.

$$CaC_2 + H_2O \quad C_2H_2 + Ca(OH)_2 \text{ ---------- } (1)$$

Fly ash is the most common pozzolanic material used as a cement substitute in concrete. The major chemical components of fly ash are SiO_2, Al_2O_3, and Fe_2O_3, which can react with $Ca(OH)_2$ to form calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) and improve many properties of concrete and mortar such as increase ultimate compressive strength, increase sulfate resistance, and reduce water permeability (Ukita et al., 1992; Sideris and Savva, 2001; Chindaprasirt et al., 2007).

The study on the use of a mixture of CCR and fly ash in concrete is not well-known and only a small amount of research has been undertaken. Krammart et al. (1996) found that CCR and fly ash mixture can produce a pozzolanic reaction, resulting in end products similar to those obtained from the cement hydration process. Jaturapitakkul and Roongreung (2003) observed a pozzolanic reaction between CCR and rice husk ash, reporting that the highest compressive strength of the resulting mortar was 15.6 MPa at 28 days. From the previous researches, it is worth noticing that mixture of CCR and pozzolanic materials have a high potential to be used as a new cementitious material in concrete. However, these studies showed that mixture of CCR and pozzolanic materials still gave low compressive strength of concrete and mortar, especially at the early strength because of the slow nature of pozzolanic reaction.

In this study, an effort will be made to evaluate the usefulness of the mixture of CCR and fly ash as a new main cementitious material instead Portland cement for producing concrete and concrete block. Three activation methods will be used to promote the reaction between CCR and fly ash reaction such as (1) co-grinding to increase the fineness of CCR and fly ash mixture; (2) chemical addition; (3) elevated temperature curing (60 °C). The fresh and hardened properties of concrete made from CCR and fly ash mixture such as heat evolution, compressive strength, and modulus of elasticity will be determined. Furthermore, the durability of concrete in term of water permeability and chloride resistance will be also investigated. For concrete block, compressive strength and water absorption were tested and all testing results will be compared with the standard specifications for concrete block.

2. Objectives

1. To develop the mixture of calcium carbide residue and fly ash as a new cementing in concrete and concrete block.
2. To investigate mechanical and durability properties of concretes made from the mixture of calcium carbide residue and fly ash in terms of compressive strength, modulus of elasticity, heat evolution, water permeability, and chloride resistance.
3. To evaluate the effect of activation methods on strength and durability of concrete made from the mixture of calcium carbide residue and fly ash.
4. To evaluate the use of the binder from the mixture of calcium carbide residue and fly ash for concrete block.

3. Scope of the Study

The CCR used in this study will be collected from the disposal area in an acetylene gas factory. Fly ash will be obtained from the Mae Moh power plant located in northern Thailand. Physical properties such as specific gravity, particle size distribution, and image of particles by scanning electron microscope (SEM) will be investigated. Chemical composition by X-Ray fluorescence (XRF) will be also studied. The optimum ratio of CCR to fly ash, 30:70 by weight, will used as a binder for casting concrete. Three activation methods included (1) co-grinding to increase the fineness of CCR and fly ash mixture; (2) chemical addition; (3) elevated temperature curing (60°C) were used in this study in order to promote the reaction between CCR and fly ash. The effects of activation methods on mechanical and durability properties of all concrete will be investigated such as compressive strength, modulus of elasticity, water permeability, heat evolution, and chloride resistance.

Concrete block mixtures will be prepared with a new cementing material from CCR and fly ash mixtures and fine aggregate. The concrete block specimens having a cross section of 10 x 10 cm^2 and a length of 20 cm will be used in this study. All concrete block mixtures will be cast by using the pressure. The compressive strength and water absorption of concrete block will be investigated. All results of concrete block will be compared with the standard specification for paving concrete block.

4. Experimental Program

4.1. Materials

The materials used in this study were CCR, FA, OPC, crushed limestone, local river sand, and superplasticizer Type F.

CCR used in this research was obtained from a disposal area of an acetylene gas industry in Samutsakorn province, Thailand. FA was collected from the Mae Moh power plant in Lumpang province, Thailand.

In this study, CCR was mixed with FA at a constant ratio of 30:70 by weight (assigned as OFC) and used as a binder for casting concrete, as suggested by a previous result of Krammart et al. (1996).

4.2. Method of Study

4.2.1. Mixture Proportions of Concrete

The mix proportions of concretes are summarized in Table 1. CCR – FA concrete mixture had a binder content of 550 kg/m^3, while OPC control concrete used 500 kg/m^3 of Portland cement type I. All concrete mixtures had a water-to-binder ratio of 0.25, and the superplasticizer was employed to control slump of fresh concrete between 150 and 200 mm. There were three activation methods to promote the strength development of a new cementing material. These activation methods are the following

(1) Chemical activation - adding 1% of sodium hydroxyl solution (NaOH) by weight of binder to enhance the pozzolanic activity of FA and CCR (assigned as OFC-C concrete).

(2) Physical activation - increasing the fineness of both CCR and FA by grinding until the particles retained on a sieve No. 325 were less than 1.1% by weight (assigned as FFC concrete).

(3) Thermal activation - curing concrete at temperature of 60 °C for 24 hours after removal from the molds (assigned as OFC-H concrete).

Concrete cylindrical specimens of 100 mm in diameter and 200 mm in height were cast and were allowed to set for 24 h. OPC, OFC, OFC-C and FFC concretes were cured in water until the date of testing to determine the compressive strength at 1, 3, 7, 28 and 90 days.

For the thermal activation, OFC-H concrete was wrapped by a plastic sheet to protect the evaporation of free water after the specimens were removed from the molds. The specimens were cured at temperature of 60 °C for 24 h, and the plastic sheet was later removed, and the specimens continued to cure in water. The compressive strengths of OFC-H concretes were determined at 3, 7, 28 and 90 days.

Table 1 - Mixture proportions of recycled aggregate concretes containing fly ash.

Mix	Mix Proportion (kg/m^3)								W/B	Slump (cm)
	CR	FA	Cement	Fine Agg.	Coarse Agg.	Water	SP*	NaOH		
OPC	-	-	500	820	1040	126	4.0	-	0.25	20.0
OCF	165	385	-	720	915	135	5.5	-	0.25	20.0
OCF-C	165	385	-	720	915	135	5.5	5.5	0.25	18.5
OCF-H	165	385	-	720	915	135	5.5	-	0.25	18.5
GCF	165	385	-	755	960	135	5.5	-	0.25	19.0

* The water in the superplasticizer is 50%

4.2.2. Testing of Specimens

In this research, the experimental program consists of 2 parts. Part I is to investigate mechanical and durability properties of concretes made from the mixture of CCR and fly ash in terms of compressive strength, modulus of elasticity, heat evolution, water permeability, and chloride resistance. Part II is utilization of the mixture of CCR and fly ash as a binder in concrete block. The details of each part are as follows :

Part I : Investigate mechanical and durability properties of concretes made from the mixture of CCR and fly ash.

In this part aimed to develop the mixture of CCR and fly ash as a new cementing in concrete. Mechanical and durability properties of all concrete will be investigated. The determined properties of concrete are compressive strength, modulus of elasticity, heat evolution, and chloride resistance. The details for each test program are summary as follows :

Compressive strength **:** The compressive strength of concrete is one of the major properties needed in most of concrete work. If the compressive strength of concrete is high, it generally means that the concrete is of high quality. The compressive strength of all concretes will be tested in accordance with ASTM C39 (2011). In this investigation, concrete cylinder specimens with 10 cm in diameter and 20 cm in height will be used to determine the compressive strength of concrete.

Modulus of elasticity **:** The modulus of elasticity of concrete is the important material property of concrete to be used in design reinforced concrete structures. It is defined as the ratio of normal stress to corresponding strain for tensile or compressive stress below the proportional limit of the material (sometime calls Young’s modulus). The modulus of elasticity of concrete (in compression) will be tested in accordance with ASTM C469 (2011). Modulus of elasticity of concrete made from the mixture of calcium carbide residue and fly ash will be compared to that of conventional concrete.

Chloride resistance **:** The rapid chloride permeability test (RCPT) of concrete as prescribe by ASTM C1202 (2011) will be used in this experiment. A slice 50 mm thick was cut from the middle of the 100 x 200 mm concrete cylinder for each mixture. The sliced concrete was then coat around with epoxy. Then, the specimen was installed in a test cell, which is the left hand side of the test cell is filled with a 3% NaCl solution and the right hand side of the test cell is filled with 0.3N NaOH solution. The system is then connected and a 60-volt DC potential is applied for 6 hours. Readings are taken every 30 minutes. At the end of 6 hours the specimen is removed from the test cell and the amount of coulombs passed through the specimen is calculated according to equation (2).

$$Q = 900(I_0 + 2I_{30} + 2I_{60} + \ldots + 2I_{300} + 2I_{330} + I_{360}) \text{ --------------------- } (2)$$

Q = charge passed (coulombs), I_0 = current (amperes) immediately after the voltage is applied, and I_t = current (amperes) at t minutes after the voltage is applied.

Corrosion of reinforcing steel in concrete **:** The corrosion of reinforcing steel in concrete was investigated in accordance with modified the NT BUILD 356 (1989). The cylindrical concrete specimens of 100 mm in diameter and 200 mm in height with a steel round bar of 12 mm in diameter and 150 mm in length at the center of cross-section of the concrete were cast. At the ages of 28 and 90 days after casting, the concretes were tested to determine the corrosion of reinforcing steel and the current flows of the concretes. The impressed voltage test set up is shown in Fig 1. Specimens were placed in a tank and then partly immersed in a 5% NaCl solution. A constant direct current (DC) potential of 12 volts was applied across the specimens, with the steel round bar being the positive electrode and a stainless steel sheet being the negative electrode. The current was measured via the voltage drop over a 10 ohm resistance, and the value was calculated in amperes using the equation for the electric circuit. The current flow was recorded every 6 h until 168 h (7 days); afterwards, the concrete specimens were split to investigate the weight loss due to corrosion of reinforcing steel in accordance with ASTM G1 (2011). To determine the weight loss due to corrosion, the reinforcing steel was immersed in acid solution at 20 – 25 °C for a period of 10 min. The surface of reinforcing steel was washed with acid solution. The acid solution used was 500 ml of hydrochloric acid with 3.5 g of hexamethylenetetramine added with reagent water to make the solution 1000 ml in volume.

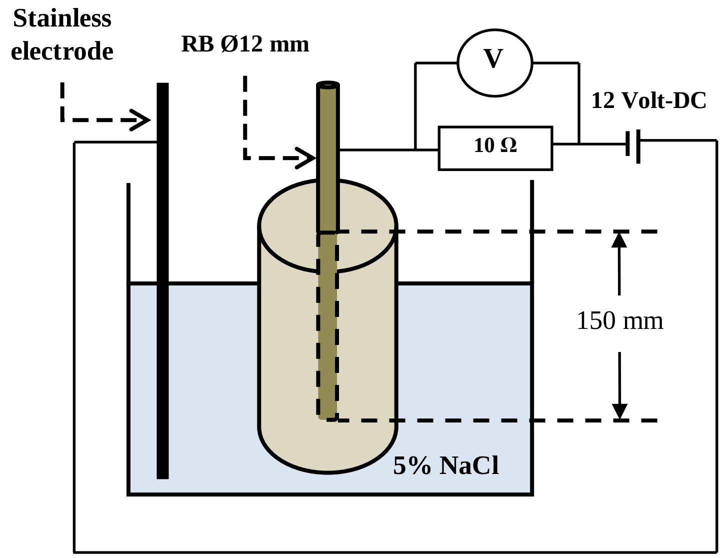

Fig. 1. Corrosion of reinforcing steel in concrete by impressed voltage test.

***Heat evolution* :** The heat evolution of concretes made from GCR-GFA mixture will be investigated under semi-adiabatic conditions. Concrete samples were cast in 450 mm cube molds lined with an insulator of 50 mm expanded polystyrene on each side or the concrete sample is 350 x 350 x 350 m^3. The heat evolution in terms of temperature rise will be measured by inserting a thermocouple at the center of the concrete specimen for a period of 168 hours (7 days) as shown in Fig. 2.

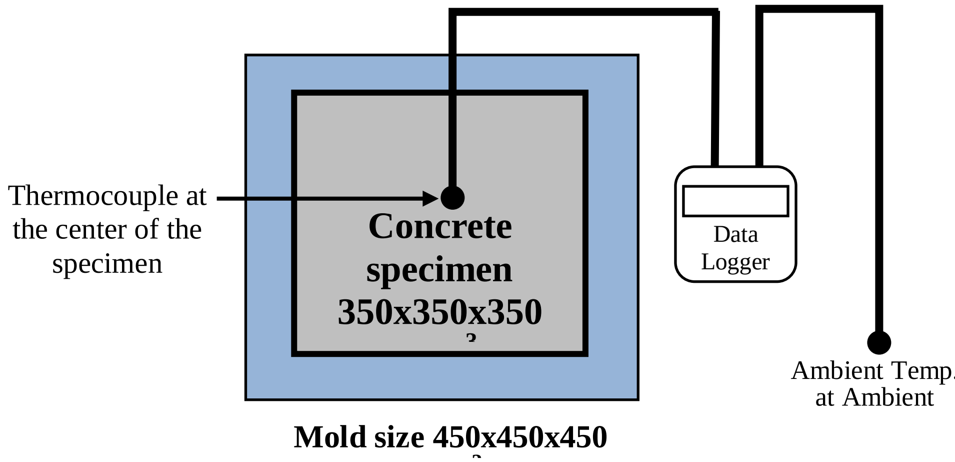

Fig. 2. Heat evaluation of concrete test.

Part II : Utilization of calcium carbide residue and fly ash mixture as a binder in concrete block

In this part aimed to utilize the mixture of CCR and fly ash as a binder for producing concrete block without Portland cement. The ratio of CCR and fly ash mixtures used in this part is the same as the concrete mixture. Concrete block mixtures will be prepared with binder (CCR and fly ash mixture), water, and fine aggregate. The concrete block specimens having a cross section of 10 x 10 cm^2 and a length of 20 cm will be used in this study. All concrete block mixtures will be cast by using the pressure. The compressive strength and water absorption of concrete block will be investigated. All results of concrete block will be compared with the standard specification for paving concrete block.

5. Results and Discussions

5.1 Concretes Made from Calcium carbide residue and Fly Ash mixture

5.1.1 Chemical and Physical Properties of Materials

The materials used in this study were CCR, FA, OPC, crushed limestone, local river sand, and superplasticizer Type F. Table 1 shows the chemical compositions materials tested by X-ray fluorescence analysis and the physical properties of the materials were shown in Table 2.

Table 1 Chemical compositions of the materials.

Chemical composition (%)	Cement (OPC)	FA	CCR	FFC
Silicon Dioxide (SiO_2)	20.9	41.9	4.3	29.0
Aluminum Oxide (Al_2O_3)	4.8	21.5	0.4	13.6
Iron Oxide (Fe_2O_3)	3.4	12.7	0.9	7.6
Calcium Oxide (CaO)	65.4	13.9	56.5	32.6
Sulfur Trioxide (SO_3)	2.7	0.6	0.1	-
Magnesium Oxide (MgO)	1.3	2.6	1.7	1.9
Sodium Oxide (Na_2O)	0.3	2.7	-	-
Potassium Oxide (K_2O)	0.4	2.5	-	-
Loss on Ignition (LOI)	2.9	5.2	36.1	10.1

Table 2 Physical properties of the materials.

Material	Specific Gravity	Retained on a Sieve No.325 (%)	Median Particle Size: d_{50} (micron)
Cement (OPC)	3.15	20.0	14.60
Original CCR-FA (OFC)	2.43	22.9	12.92
Ground CCR-FA (FFC)	2.73	1.1	2.93

CCR used in this research was obtained from a disposal area of an acetylene gas industry in Samutsakorn province, Thailand. The main chemical of CCR were 32.6% of CaO and 36.1% of LOI. It was found that the value of LOI of CCR was very high because CCR was rich in $Ca(OH)_2$; the value of LOI in CCR was tested over the temperature range of 750 °C. Generally, $Ca(OH)_2$ was decomposed into CaO and H_2O (gas) at a temperature of approximately 550 °C (Jaturapitukkul and Roongreung 2003).

FA was collected from the Mae Moh power plant in Lumpang province, Thailand. The total oxide contents of SiO_2, Fe_2O_3, and Al_2O_3 was 76.1% and it can be cetegorized as class F fly ash as specified by ASTM C618 (2011).

In this study, CCR was mixed with FA at a constant ratio of 30:70 by weight (assigned as OFC) and used as a binder for casting concrete, as suggested by a previous result of Krammart et al. (1996). As seen from Table 2, the specific gravity of OFC was 2.43, while that of ordinary Portland cement was 3.15. The median particle size (d_{50}) of OFC was 12.92 microns, and the particles retained on a sieve No. 325 were 22.9% by weight. Ordinary Portland cement had the median particle size of 14.60 microns and the particles retained on a sieve No. 325 was 20.0% by weight. After grinding to increase the fineness of CCR and FA (assigned as FFC), the particles retained on a sieve No. 325 of FFC was reduced to 1.1% by weight. The median particle size of the binder was reduced from 12.92 (OFC) to 2.93 (FFC) microns, while the specific gravity increased from 2.43 (OFC) to 2.73 (FFC).

5.1.2 Compressive strength of concrete

The compressive strength of concrete was reported in Table 3. The results showed that the compressive strength of concrete using CCR and FA mixture as a binder increased with curing age similar to that of Portland cement concrete. OFC concrete had compressive strengths of 2.6, 4.2, 7.7, 19.7 and 30.6 MPa at 1, 3, 7, 28 and 90 days, respectively. The compressive strength of OFC concrete is lower than the concrete using OPC at all test ages. This property is due to the compressive strength of OFC concrete based only on the pozzolanic reaction between CCR and FA. Similar results were obtained by Makaratat et al. (2010), who found that the compressive strength of concrete using FA and CCR without Portland cement was lower than that of OPC concrete, especially at the early age. Fig. 3 shows the relationship between the compressive strength and the curing age of concrete. The results also showed that the compressive strength of concretes using CCR and FA as a binder could be improved by all of the activation methods. The compressive strengths of concretes with all activation methods were higher than the concrete without activation method at both early and later ages. The compressive strengths of concretes using CCR and FA mixture with various activation methods ranged from 21.0 - 37.4, 34.0 - 55.0, and 37.9 - 65.1 MPa at 7, 28 and 90 days, respectively.

Table 3 Compressive strength and normalized compressive strength of the concretes.

Mix	Compressive Strength (MPa) – ***Normalized Compressive Strength (%)***				
	1 Day	3 Days	7 Days	28 Days	90 Days
OPC	28.0 – ***100***	38.9 – ***100***	43.5 – ***100***	51.3 – ***100***	58.3 – ***100***
OFC	2.6 – ***9***	4.2 – ***11***	7.7 – ***18***	19.7 – ***38***	30.6 – ***52***
OFC-C	5.5 – ***20***	13.4 – ***34***	21.0 – ***48***	34.0 – ***66***	37.9 – ***65***
OFC-H	2.6 – ***9***	27.3 – ***70***	27.9 – ***64***	37.2 – ***72***	44.2 – ***76***
FFC	10.6 – ***38***	23.4 – ***60***	37.4 – ***86***	55.0 – ***107***	65.1 – ***112***

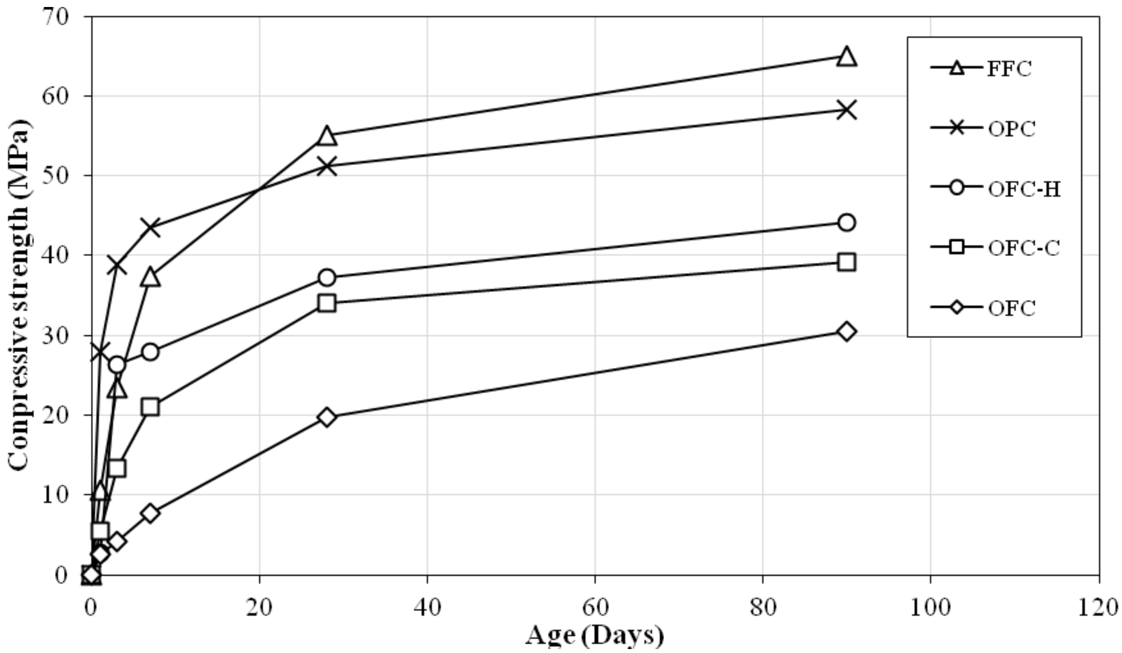

Fig. 3 Relationship between the compressive strength and the curing age of concrete.

The addition of 1% NaOH into a new binder could improve the reactivity between CCR and FA. The addition of NaOH in the binder increased in leaching of silica and alumina from the FA particles (Rattanasak and Chindaprasirt 2009), thereby increasing the reaction with $Ca(OH)_2$ from CCR. This result also revealed that NaOH was effective in promoting the reaction between CCR and FA. Thus, NaOH could be used to improve the compressive strength of concrete, but the compressive strength of OFC-C concrete was still lower than that of the OPC concrete. However, OFC-C concrete had higher compressive strength than OFC concrete at both the early and later ages because the products of C-S-H and C-A-H increased with the addion of NaOH, thereby increasing the strength of the paste (Hanjitsuwan et al. 2014). The OFC-C concrete, from which 1% of NaOH was used as an activated strength, had a compressive strength that increased from 48% of the OPC concrete at 7 days to 66% of the OPC concrete at 28 days, while the OFC concrete without NaOH had a compressive strength at 7 days and 28 days of 7.7% and 29.7% of OPC concrete, respectively. Thus, adding 1% of NaOH in concrete can be used to improve the compressive strength of concrete from which CCR and FA was used as a binder.

The elevated curing temperature of 60 °C for the binder from CCR and FA also improves the compressive strengths of concrete. The compressive strengths of OFC-H concrete at 3 and 7 days were 27.3 and 27.9 MPa, respectively and increased to be 37.2 and 44.2 MPa at 28 and 90 days, respectively. In other words, the pozzolanic reaction was increased with the elevated curing temperature. Moreover, the compressive strength development rate was faster at the early ages but was not significantly improved at the later ages, because during the initial period of the elevated curing period, the formation of pozzolanic reaction products had a physical structure less compacted and higher unfilled pore structure and led to a lower development of strength at the later ages when compared to the one cured at lower temperature (Benammara et al. 2013). This behavior is in agreement with the result of Kim et al. (2002). The current results showed that the increased curing temperature increased faster strength development rates at the early ages and then increased gradually at the later ages.

The best method to improve the compressive strength of concrete was to increase the activated strength by increasing fineness of both CCR and FA via grinding, it was the most effective method to increase the compressive strength of concrete. Although FFC concrete produced lower compressive strength than OPC concrete at the early ages between 1 and 7 days, its compressive strength was approximately 86% of OPC concrete a 7 days. Thereafter, the compressive strength of FFC concrete was greater than that of OPC concrete. For example, the compressive strength of FFC was 55.0 MPa at 28 days and increased up to 64.1 MPa at 90 days and could be classified as a high strength concrete, whereas the strength of OPC concrete were 51.3 and 58.3 MPa at the ages of 28 days and 90 days, respectively. This finding is observed because the small particles sizes of both CCR and FA had high surface area and also improved the pozzolanic reaction. Moreover, the small particles of FFC could fill up the voids between the cement and the aggregate, thus increased the compressive strength of FFC concrete (Jaturapitakkul et al. 2011).

These findings indicated that the mixture of CCR and FA with various activation methods could be used as a new cementitious material to produce concrete without using Portland cement. These three activation methods, i.e., adding 1% of NaOH, increasing fineness of binder, and curing at temperature of 60 °C for 24 h could improve the compressive strength of concrete to be higher than OFC concrete. Moreover, increasing the fineness of the binder produced the highest compressive strength of the concrete. In addition, FFC concrete could produce the compressive strength of more than 55 MPa at 28 days.

5.1.3 Modulus of Elasticity

The modulus of elasticity (E values) of CCR and FA concrete with various activation method at age of 28 and 90 days are indicated in Fig. 4. It shows that the elastic modulus of concrete made from CCR and FA mixture with and without activation methods increased with curing age as same as concrete made from OPC. The E values of CCR-FA concretes were in the range of 38.1 and 60.8 GPa while that of the OPC concrete was 63.1 and 65.4 GPa at 28 and 90 days, respectively. This result showed that the OCF concrete without activation method had very low modulus of elastic, this is due to OCF concrete had still low compressive strength. However, all activation methods can improve both compressive strength and elastic modulus. For example, the elastic modulus at 28 days of OCF-C, OCF-H and GCF concretes were 46.8, 52.4 and 55.5 GPa, respectively, while their compressive strength at the same age were 34.0, 37.2 and 55.0 MPa respectively. As a result, all activation methods had no significant effects on elastic modulus, depending on its compressive strength.

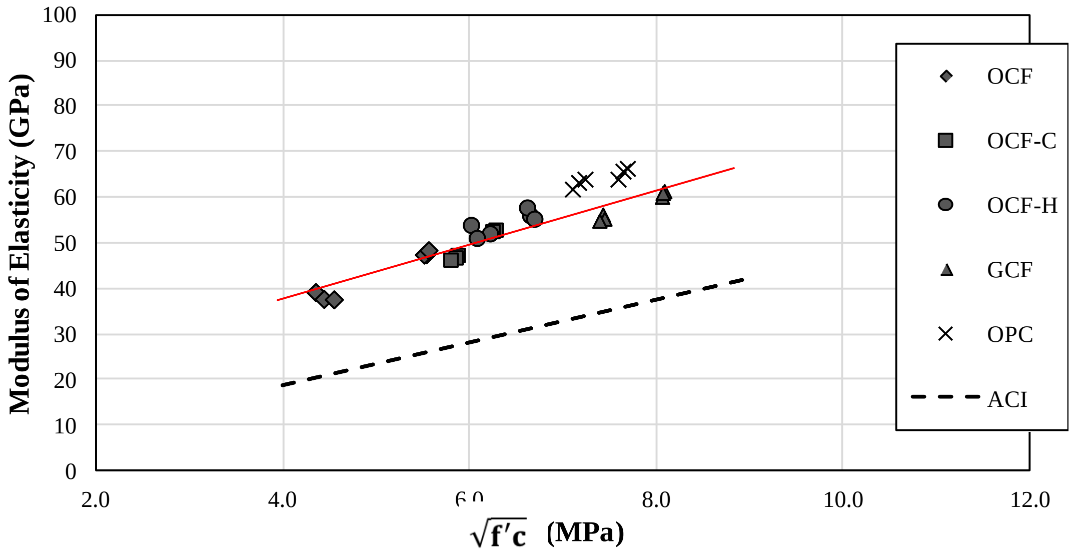

Fig. 4. Relationship between modulus of elasticity and square root of compressive strength of concrete.

Fig. 4 shows the relationship between E values and square root of compressive strength of concrete from this experiment compared with values predicted by ACI 318 (2012). The modulus of elasticity of concrete made from CCR and FA had related to square root of compressive strength similar trend of concrete made from OPC. It should be noted that the E value of both CCR-FA concretes and OPC concrete in this experiment had higher than the value suggested by ACI 318 (2012). This may be E values of all concrete in this investigate were determined from concrete cylinders of 100 mm in dimeter and 200 mm in height, it was smaller than the standard specimen. The smaller size of specimen was obtained the E values greater than larger size specimen (Rashi et al, 2002). However, all of concrete made from CCR and FA as a binder can be used equation that recommended by ACI 318 (2012) to predicted the E values of concretes similar the conventional concrete.

5.1.4 Chloride resistance of concrete

The total charge passed through the concrete samples in terms of coulombs, according to ASTM C1202 (2012), is shown in Fig. 5. The OFC concrete had an amount of total charge passed more than that of OPC concrete at the age of 28 days because: the total charge passed of OFC concrete was 1283 coulombs, whereas that of OPC concrete was 1094 coulombs. The higher charge passed of the OFC concrete may be to the low compressive strength of OCF concrete. Moreover, the total charge passed of concrete decreased with the compressive strength increased of concrete strength as well as the increased of curing age of concrete. Note that, the total charge passed at 90 days of OFC concrete was 355 coulombs, or approximately 40% of OPC concrete (OPC concrete had total charge passed of 883 coulombs), because the total charge passed and porosity of OFC concrete were reduced with age due to pozzolanic reaction. The C-S-H product from the pozzolanic reaction could reduce the chloride ion penetration because C-S-H could absorb chloride ions on the surface (Filho et al. 2012). However, the reaction between CCR and FA was a pozzolanic reaction and the reaction was very slow and took a longer period than the hydration reaction of cement. Thus, the total charge passed of OFC concrete decreased to be lower than OPC concrete at the later age of 90 days.

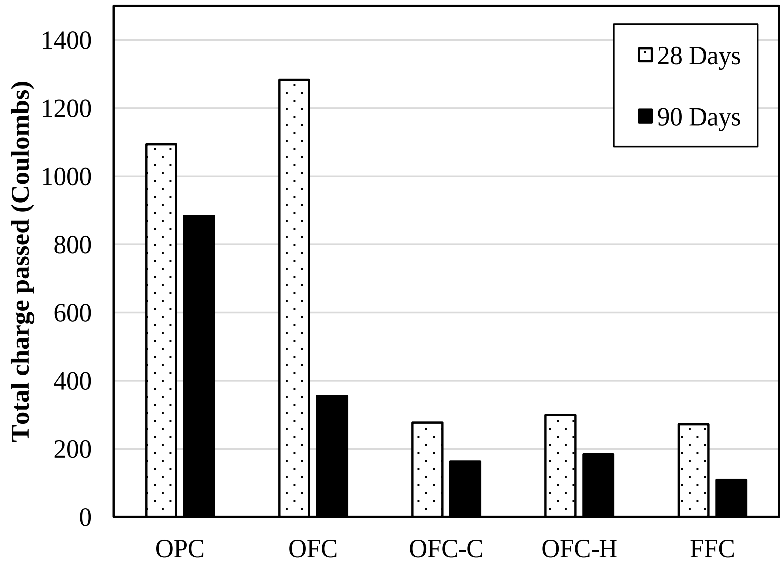

Fig. 5. Total charge passed of the concretes.

These data clearly seen that all activated concretes had lower chloride ion penetration than OPC concrete at both 28 and 90 days. The results also showed that the chemical activated strength by adding 1% of NaOH had significantly affected the increase of the chloride resistance of concrete. The total charge passed of OFC-C concrete was lower than OPC concrete at 28 and 90 days and was only 277 and 163 coulombs or approximately 25% and 18% of the OPC concrete, respectively. This result may be due to the effect of adding of 1% of NaOH in the binder had affected on leaching of silica and alumina from the FA particles, enabling reaction with $Ca(OH)_2$ from CCR and increasing the amounts of the pozzolanic products (C-S-H and C-A-H), thereby resulting in the increase of the chloride ion penetration resistance of the concrete.

In the case of concrete with thermal activated strength, it had lower chloride ion penetration resistance compared with the increased fineness of binder and the chemical activation methods. The total charge passed of OFC-H concrete at 28 days was 27% of the OPC concrete. At the later age, the total charge passed slightly reduced and was 21% of the OPC concrete at 90 days due to elevated curing temperature produces a non-uniform distribution of C-S-H product. This result confirms the findings of Benammara et al. (2013), who found that the porosity of concrete was increased with the increased of curing temperature and the CSH products were less homogeneous in the cement paste matrix, allowing for the development of a larger pore network.

It was observed that FFC concrete had the lowest total charge passed because FFC concrete had small particle sizes of the binder, which improved concrete strength as well as reducing the water permeability. Moreover, FFC concrete had a cumulative charge passed classified as a low to very low values when compared with ASTM C1202 (2012). At 90 days, the total charge passed of FFC concrete was only 109 coulombs.

Fig. 6 shows the relationship between the total charge passed and the compressive strength of concrete. The concrete had higher chloride resistance when the compressive strength increased. Srisen (2013) and Yanga and Chianga (2005) also found similar results in ordinary Portland cement concrete. At 90 days, all concretes from a binder of CCR and FA had total charge passed lower than OPC concrete although it had lower compressive strength than OPC concrete. Nevertheless, OFC concrete without strength activated had total charge passed of 1283 coulomb which was higher than OPC concrete at 28 days and it can be classified as low chloride ion penetrability according to ASTM C1202 (2012). Note that all of CCR and FA concretes had much lower chloride ion penetration at the later ages than at the early ages. This phenomenon may be the result of the proportion of fly ash in the binder improving the chloride binding capacity of hardened concrete. Many studies (Leng et al. 2000; Taleroa et al. 2011) reported that fly ash could reduce chloride ion penetration due to both the chemical and physical properties. Moreover, the chloride ion could react with the reactive alumina oxide from the partly chemical component of fly ash and the calcium hydroxide from the CCR contributing to the formulation of Friedel's salt.

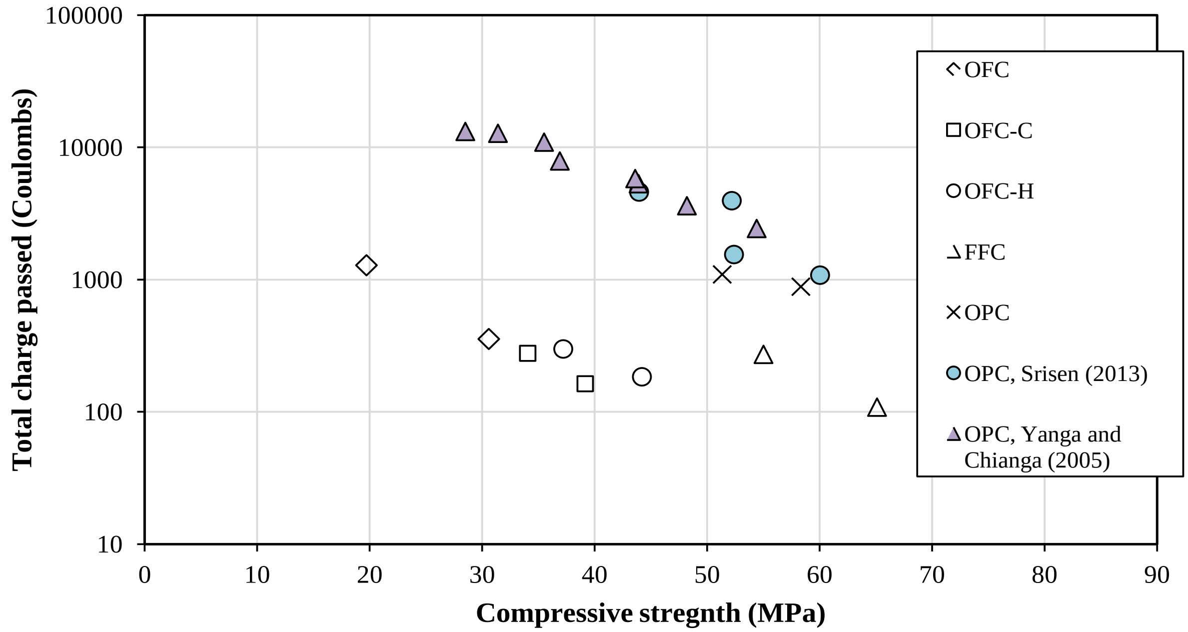

Fig. 6 Relationship between total charge passed and compressive strength of concrete.

Furthermore, chloride ion penetration could be reduced due to physical binding, in which chloride ions were absorbed on the surface of C-S-H, thereby reducing the chloride ion ingress by the electrostatic attraction from the surface of hydrated product (Filho et al. 2012). Thomas et al. (2012) investigated the chloride binding in hardened cement paste of concrete containing ordinary Portland cement with various pozzolanic materials. They found that the increase in the level of replacement of fly ash and slag could increase the chloride binding capacity. In this research, the binder is from CCR and FA, with 70% by weight of the binder being fly ash. This finding also explains why concrete using CCR and FA as a binder had higher chloride penetration resistance than the OPC binder. In addition, the use of NaOH activation was very effective to reduce the chloride ion penetration because Na^+ ions could adsorb Cl^- ions due to electrostatic attraction and bind the chloride ions onto the surface of paste, i.e., Na^+ ions have a positive charge that enables it to absorb the Cl^- ions (Lloyd et al. 2010; Hossain et al. 2015).

5.1.5 Corrosion of reinforcing steel in concrete

The relationships between the current passed of concrete and the immersed time of concrete at 28 and 90 days are reported in Figs. 7 and 8, respectively. The current flow was attributed to the electrical resistance and chloride permeability resistance of the concrete. The current was increased by the chloride permeability, and corrosion occurred when the chloride ions reached the reinforcing steel in concrete. At 168 h after the impressed current, the concrete specimens were broken to determine the corrosion of reinforcing steel. The final current was used to indicate corrosion current rate of the reinforcing steel in the concrete. The final current values at 28 days of OFC, OFC-C, OFC-H, and FFC concretes were 30, 9, 6 and 6 mA, respectively, while that of the OPC concrete was 18 mA, similar trend in chloride permeability. As seen from Fig. 7, OFC concrete had a lower final current than OPC concrete and had higher final current flow than OPC concrete after the OFC concrete had been cracked. The time of the first crack of OFC concrete was 138 h. Similar results were also obtained by Sangoju et al. (2011) who stated that the charge passed and chloride ion penetration were increased when the crack width of concrete was increased. Note that the current flow values of concretes from a binder of CCR and FA mixture were lower than that of OPC concrete for all activation methods as well as for increased of curing age and compressive strength. At 90 days, the final current values of OFC, OFC-C, OFC-H and FFC concretes were reduced to 5, 3, 3 and 2 mA, respectively, while OPC had a final current value of 13 mA.

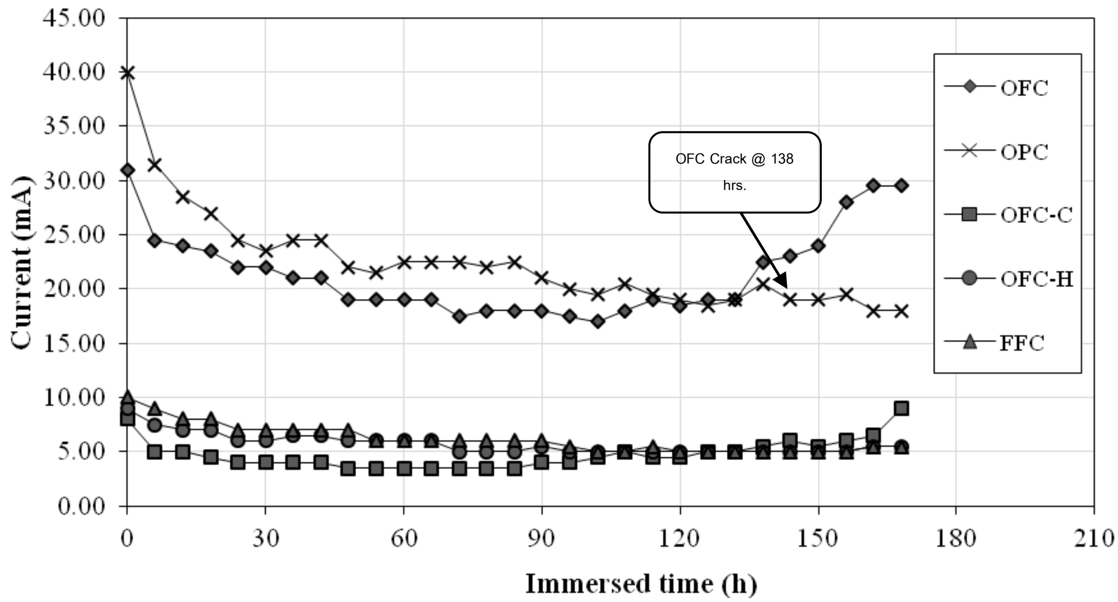

Fig. 7 Current flow of concrete at the curing age of 28 days.

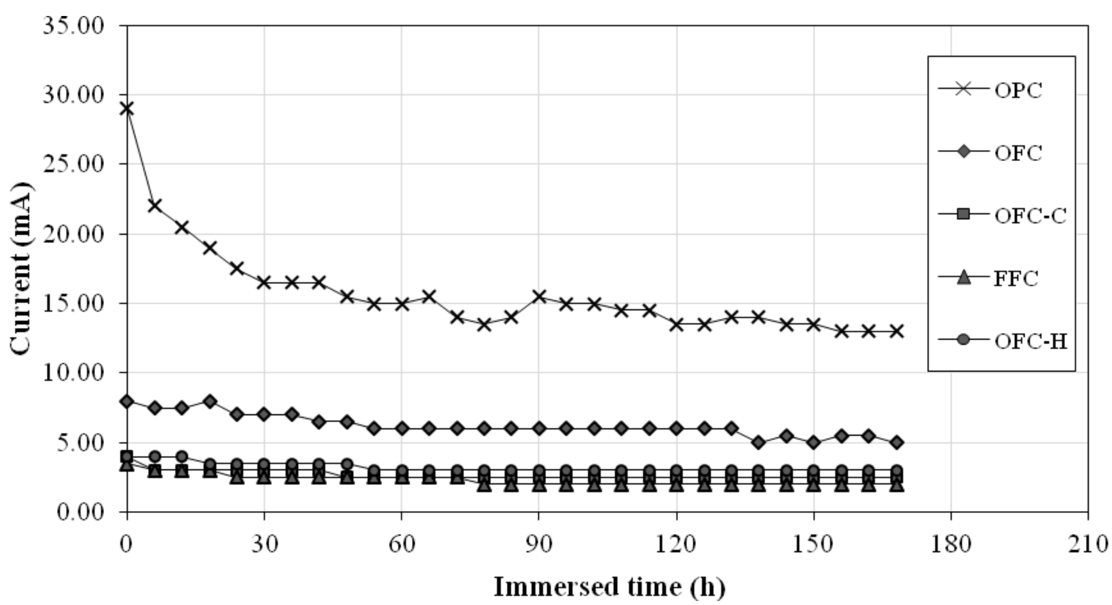

Fig. 8 Current flow of concrete at the curing age of 90 days.

The result of the impressed voltage test according to NT Build 356 (1989) had a similar trend as that of the total charge passed in according with ASTM C1202 (2012), i.e., the higher is the compressive strength thus lower is the final current value, as shown in Figs. 9 and 10. The results indicated that the concrete using CCR and FA as a binder had lower total charge passed and final current than OPC concrete although it had lower compressive strength, as confirmed by the test results from Fig. 5. Cheewaket et al. (2010) reported that the selection of concrete mixture in order to reduce chloride penetration also depends on the prevention of the ingress of chloride due to type of binder of concrete and it was not proper to consider only strength and permeability resistance of the concrete.

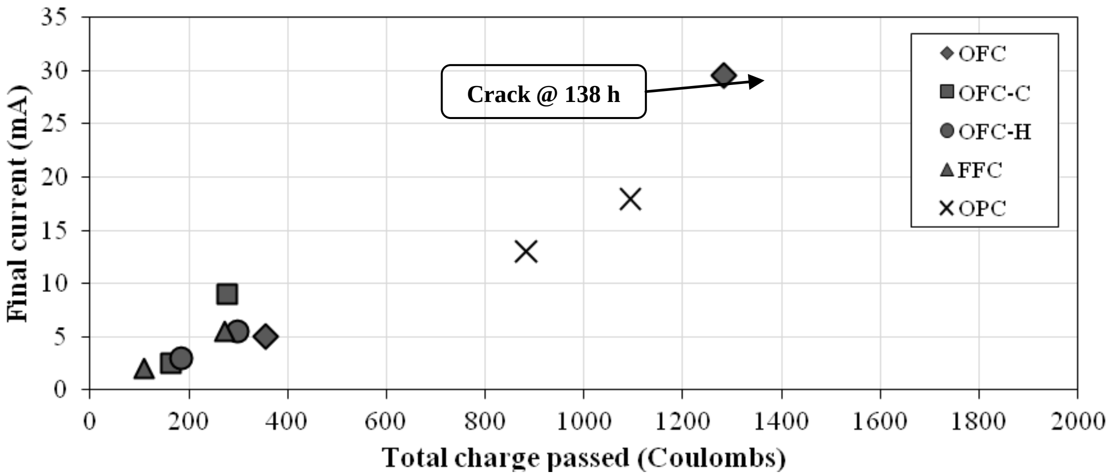

Fig. 9 Relationship between the final current and the total charge passed of concrete.

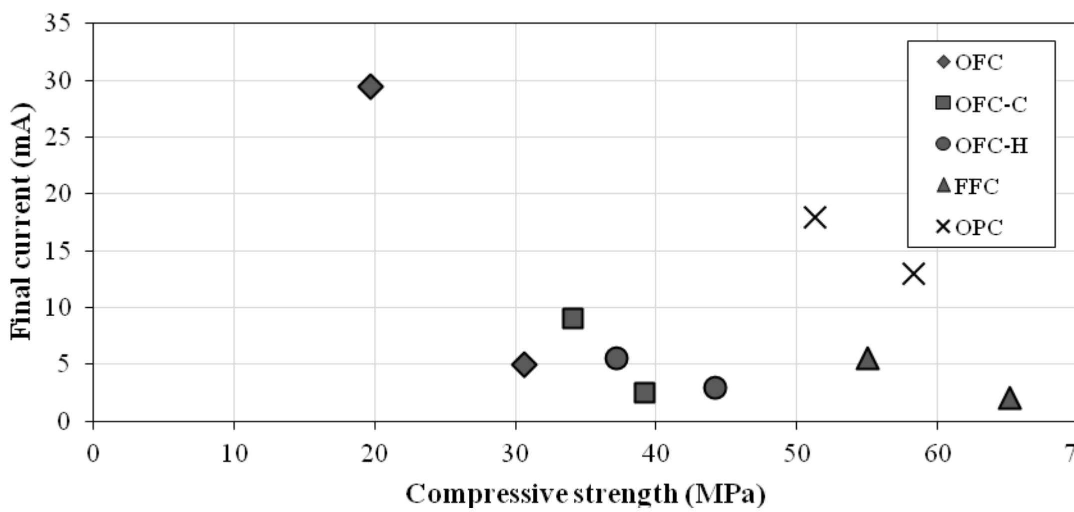

Fig. 10 Relationship between final current and the compressive strength of concrete.

After the impressed voltage test, the corrosion of reinforcing steel in concrete specimens was examined. The damaged due to steel corrosion and percentage weight loss of reinforcing steel in concrete at 28 and 90 days are shown in Figs. 11a and 11b, respectively. The results showed that the OFC had higher weight loss of reinforcing steel than that of OPC concrete at 28 days. This result may be related to the low compressive strength of OFC concrete. OFC concrete had a weight loss of reinforcing steel of 2.31%, and its compressive strengths was 19.7 MPa at 28 days, while OPC concrete had weight loss of reinforcing steel of 1.80% and had the compressive strength of 51.3 MPa at 28 days. Moreover, OFC concrete was cracked at 138 h after testing. Because the volume of rusted steel was 2 - 2.5 times higher than the volume of original reinforcing steel, the rusted steel caused an internal tensile force that was higher than the tensile strength of concrete; as a result cracks and splits off the concrete were occurred (Arya and Xu 1995). In addition, after the OFC concrete was cracked, the corrosion increased very rapidly due to easily access of oxygen, moisture and further aggressive agents through crack. However, OFC concrete could reduce weight loss of reinforcing steel at 90 days, similar to the reduction of the final current flow and the total charge passed of concrete.

OPC		**W_L = 1.80%**
OFC		**W_L = 2.31%**
OFC–C		**W_L = 1.53%**
OFC–H		**W_L = 1.67%**
FFC		**W_L = 0.79%**

(a) Concrete at 28 days.

OPC		**W_L = 1.32%**
OFC		**W_L = 1.20%**
OFC–C		**W_L = 0.91%**
OFC–H		**W_L = 1.05%**
FFC		**W_L = 0.68%**

(b) Concrete at 90 days.

Fig. 11 Corrosion of reinforcing steel in concrete.

OFC concrete could reduce the charge passed, but it did not significantly reduce the corrosion of reinforcing steel in the concrete. However, adding 1% NaOH, curing at a temperature of 60 °C, and increasing fineness of the binder could decrease corrosion in terms of the weight loss of the reinforcing steel. The use of NaOH to activate strength of concrete could also reduce corrosion of reinforcing steel in concrete. This reduced corrosion may be due to the ability of NaOH solution in OFC-C concrete to reduce the free chloride content. Similar results were also found by Chindaprasirt and Chalee (2014), who studied the effect of NaOH on steel corrosion of fly ash-based geopolymer concrete. They reported that the use of high NaOH concentration in geopolymer concrete could decrease corrosion of reinforcing steel in concrete when compared with concrete with lower NaOH concentration because the use of high NaOH concentration increased the chloride binding capacity of concrete and led to reduction of the free chloride content. Moreover, Saraswathy et al. (2003) studied the effect of various activation techniques of concrete blended fly ash and found that the use of chemical activation with sodium hydroxide solution was highly effective to reduce the corrosion rate and free chloride of concrete.

OFC-H concrete had percentage weight loss due to corrosion of reinforcing steel in concrete less than those of the OFC and OPC concretes, but it had higher weight loss than the OFC-C concrete; this result was consistent with the rapid chloride penetration test. In addition, increasing the fineness of the binder appeared to be the most effective activation method when compared with chemical and thermal activation methods. FFC concrete had the lowest corrosion of reinforcing steel in concrete at both the early and later ages. This behavior is observed because the small particle sizes of both CCR and FA increase the pozzolanic reaction and reduce the pore structure by reducing the pore size (Sinsiri et al. 2010). This reduced pore size inhibits the penetration of water and oxygen into concrete.

5.2 Concretes Made from Calcium carbide residue and bottom Ash mixture

5.2.1. Chemical and Physical Properties of Materials

Physical properties of the materials are presented in Table 4. It showed that OPC had the specific gravity, the percentage of particle retained on a sieve No. 325 (45µm), and the median particle size (d_{50}) of 3.15, 16.82%, and 14.7 µm, respectively. While the specific gravity and the percentage of particle retained on a sieve No. 325 (45µm) of BA and CR are 2.33, 2.32 and 96.33, 53.96%, respectively. After the BA and CR were ground to increase the fineness (GBA and GCR), their specific gravity are increased to 2.75 and 2.66, respectively while the percentage of particle retained on a sieve No. 325 (45µm) and the median particle size (d_{50}) of GBA and GCR are 3.95, 9.85% and 2.40, 2.87 µm, respectively.

Table 4 Physical properties of materials

Materials	Specific gravity	Particles retained on a sieve No. 325 (45µm) (%)	Median particle size, d_{50} (µm)
OPC	3.15	16.82	14.7
BA	2.33	96.33	-
CR	2.32	53.96	-
GBA	2.75	3.95	2.4
GCR	2.66	9.85	2.87

Chemical compositions of OPC, GBA, and GCR are shown in Table 5. The major chemical compositions of OPC were 65.4, 20.9, 4.8 and 3.4% of CaO, SiO_2, Al_2O_3, and Fe_2O_3, respectively. In case of GBA, the total amount of SiO_2, Al_2O_3, and Fe_2O_3 was 70.1%, nearby the minimum requirement of 70.0% as defined by ASTM C618 (2011) for fly ash Class F. In addition, these results also showed that the chemical compositions of GBA were similar to those of fly ash which was obtained from the same source (Chindaprasirt and Rukzon, 2008). While the major chemical compositions of GCR was 59.8% of CaO with high value of loss of ignition (LOI) of 26.9%. This high LOI value is analogous to the result of Rattanashotinunt et al.

(2013), which was 36.1%. This is due to the determining of LOI used temperature at 750 ± 50 °C from which $Ca(OH)_2$ in CR was decomposed into CaO and H_2O (gas) (Jaturapitakkul and Roongreung, 2003) and high loss of ignition was obtained.

Table 5 Chemical compositions of materials

Chemical composition (%)	GBA	GCR	OPC
Silicon dioxide (SiO_2)	35.6	5.2	20.9
Aluminum oxide (Al_2O_3)	19.6	2.5	4.8
Ferric oxide (Fe_2O_3)	14.9	2	3.4
Calcium oxide (CaO)	18.7	59.8	65.4
Sulfur trioxide (SO_3)	1.7	1	2.7
Magnesium oxide (MgO)	2.4	2.1	1.3
Sodium oxide (Na_2O)	1.2	0.4	0.3
Potassium oxide (K_2O)	2.3	0.3	0.4
Loss of ignition (LOI)	3.6	26.9	2.9

5.2.1 Compressive strength

Table 6 presents the average compressive strength of three concrete specimens. The results showed that the compressive strengths of CT concretes varied from 43.0 MPa in 0.5CT concrete to 68.2 MPa in 0.3CT concrete and 45.9 MPa in 0.5CT concrete to 70.3 MPa in 0.3CT concrete at 28 and 90 days, respectively.

The compressive strength of BC concrete also increased with the age of curing. The compressive strengths of BC concretes varied from 16.1 MPa in 0.5BC concrete to 29.7 MPa in 0.3BC concrete at 28 days and increased to 19.7 to 36.8 MPa at 90 days, respectively. The compressive strength development of BC10 was similar in a way of BC concrete, but its compressive strength was higher than BC concrete with the same W/B ratio. At 28 days, BC10 concrete had various compressive strengths of 24.6 MPa in 0.5BC10 concrete to 44.3 MPa in 0.3BC10 concrete and increased to 28.4 in 0.5BC10 concrete to 51.4 MPa in 0.3BC10 concrete at 90 days. The added 10% of

OPC by weight could increase the compressive strength of BC concrete by approximate 30% when the same of W/B ratio of concrete was used.

Table 6 Compressive strength of concrete

Concrete	Compressive strength (MPa) – ***(Relative Compressive Strength (%))***			
	7 days	28 days	60 days	90 days
0.3CT	56.2-***(100)***	68.2-***(100)***	68.8-***(100)***	70.3-***(100)***
0.3BC	21.4-***(38)***	29.7-***(43)***	33.2-***(48)***	36.8-***(52)***
0.3BC10	34.7-***(62)***	44.3-***(65)***	47.1-***(68)***	51.4-***(73)***
0.4CT	38.2-***(100)***	46.9-***(100)***	47.5-***(100)***	51.2-***(100)***
0.4BC	16.6-***(44)***	25.8-***(55)***	29.9-***(63)***	31.0-***(61)***
0.4BC10	23.8-***(62)***	32.9-***(70)***	39.5-***(83)***	41.9-***(82)***
0.5CT	36.0-***(100)***	43.0-***(100)***	46.0-***(100)***	45.9-***(100)***
0.5BC	10.7-***(30)***	16.1-***(37)***	18.5-***(40)***	19.7-***(43)***
0.5BC10	15.7-***(44)***	24.6-***(57)***	26.2-***(57)***	28.4-***(62)***

Compared with CT concrete at the same W/B ratio and testing ages of 28 and 90 days, the compressive strengths of BC and BC10 concretes were less than the CT concrete by approximate 35 to 70% and 20 to 55%, respectively. This is due to the compressive strength of BC was obtained mainly by pozzolanic reaction between calcium hydroxide ($Ca(OH)_2$) from GCR and siliceous or siliceous and aluminous oxides from GBA to produce calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) products, which is usually much slower rate than the hydration reaction of OPC and similar results were found by many researchers (Jaturapitakkul and Roongreung, 2003; Makaratat et al, 2010; Rattanashotinunt et al, 2013). In addition, the finer of GBA and GCR particles compared with OPC may produce the compressive strength of concrete by packing effect, especially at the early age of concrete (Tangpagasit et al, 2005; Poon et al, 2006; Kroehong et al, 2011). However, the compressive strength of the concrete made from BC cementing material could be accelerated and increased by added 10% of OPC by weight, which could be observed from the compressive strengths of BC10 concrete were 57-70% and 62-82% of CT concrete at 28 and 90 days, respectively.

Fig. 12 shows the relationship between compressive strength of concrete at 28 days and W/B ratio of concrete. For W/B ratios of 0.3, 0.4 and 0.5, BC concretes had the compressive strengths of 29.7, 25.8 and 16.1 MPa at 28 days, respectively, while those of BC10 concretes had the compressive strengths of 44.3, 32.9 and 24.6 MPa at 28 days, respectively. This behavior is similar to that of CT concrete from which, the compressive strengths of CT concretes at 28 days were 68.2, 46.9 and 43.0 MPa with the W/B ratios of 0.3, 0.4 and 0.5, respectively. The results suggested that the concrete at a lower W/B ratio (W/B ratio of 0.3) in BC and BC10 concrete mixtures promoted higher compressive strengths than those with higher W/B ratios (W/B ratios of 0.4 and 0.5) which is in a way similar to CT concrete. This result also agreed with that of Makaratat et al. (2011), who reported that the compressive strength development of concrete use fly ash mixed with calcium carbide residue as a cementing material significantly increased with a low W/B ratio.

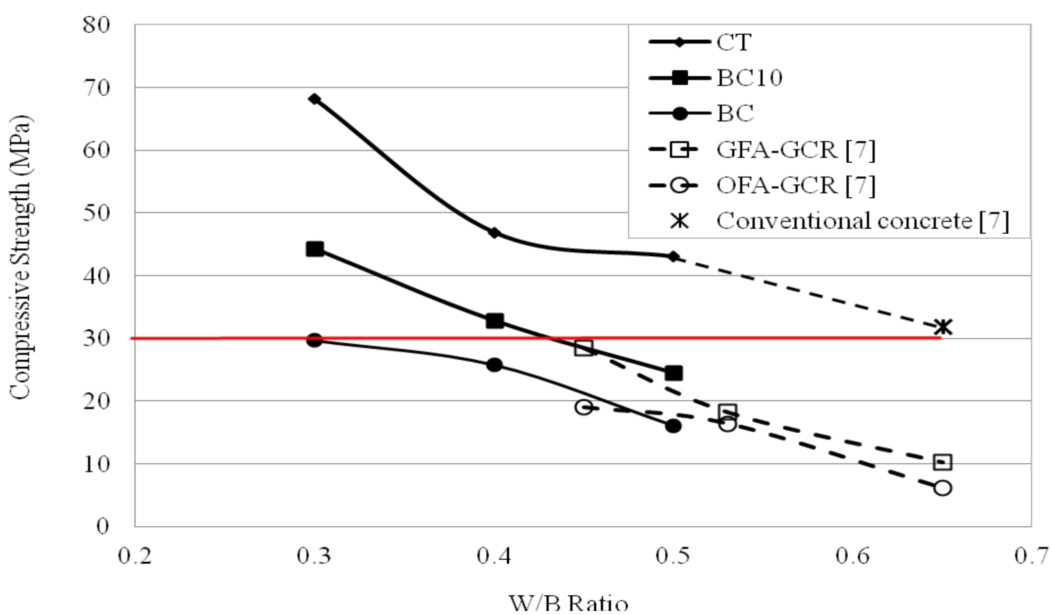

Fig. 12 Relationship between compressive strength at 28 days and W/B ratio of concrete

From the above result, the W/B ratio is a very important factor affecting on compressive strength of BC and BC10 concretes same as conventional concrete, since it is significantly controlling the rate of pozzolanic reaction development both of GBA and GCR materials. According to Lam et al. (2000) the high amount of water caused to dilute of Ca^{++} concentration and reduced the contact between the particles. In addition, Duval and Kadri (1998) reported that the kinetics of pozzolanic reaction was reduced with the increased of W/B ratio. On the other hand, the concrete with lower W/B ratio decreased the porosity in concrete, resulting in increased in the compressive strength (Živica, 2009). Moreover, when compared to concrete using original fly ash (OFA) or ground fly ash (GFA) mixed with GCR as a cementing material, the compressive strength of BC10 concrete tended to be similar to GFA-GCR concrete while that of BC concrete tended to be similar to OFA-GCR concrete. This result indicated that ground fly ash (high fineness) can react more rapidly with GCR than GBA.

From the above results, the waste material of GBA is not an inert material since it can react with the waste material of GCR and can be used as a cementing material without OPC in concrete. The cementing material can produce the compressive strength by using pozzolanic reaction. Nevertheless, the compressive strength of the concrete was less than that obtained from CT concrete with the same of W/B ratio. However, the compressive strength of 0.3BC concrete was in the same range of conventional concrete with W/B ratio of 0.7 (See Fig. 12), from which the compressive strengths of both concretes were approximately of 30 MPa at 28 days.

It should be noted the 0.3BC concrete did not have any OPC in the mixture while conventional concrete contained OPC of 300 kg/m^3. Moreover, the compressive strengths of 0.3BC and 0.4BC concretes at 28 days and 0.5BC concrete at 60 days were higher than the minimum requirement for structural concrete member of 17.2 MPa (2500 psi) specified by ACI 318 (2008). In addition, the compressive strength of BC concrete could be accelerated and increased by added 10% of OPC by weight of cementing material and reduced the W/B ratio of the concrete to achieve the high compressive strength. For example, 0.3BC10 concrete gave the compressive strength of 51.4 MPa at 90 days and its compressive strength was in the same range of 0.4CT concrete which had the compressive strength of 51.2 MPa at 90 days. Also, the compressive strengths of 0.4BC10 and 0.5CT concretes were 41.9 and 45.9 MPa at 90 days, respectively.

5.2.3 Modulus of elasticity

The modulus of elasticity of CT, BC and BC10 concretes with the W/B ratios of 0.3 to 0.5, were determined at 28, 60, and 90 days based on 100x200 mm cylinder concrete specimen. The CT concretes had modulus of elasticity range of 41.0 to 41.8, 36.1 to 38.4, and 35.2 to 35.4 GPa, with the W/B ratios of 0.3, 0.4 and 0.5, respectively. For BC concretes, the modulus of elasticity ranged from 30.0 to 32.6, 28.9 to 31.5 and 25.6 to 26.5 GPa, with the W/B ratios of 0.3, 0.4 and 0.5, respectively. While the modulus of elasticity of BC10 concretes ranged from 35.3 to 35.9, 31.6 to 33.3, and 26.8 to 30.2 GPa with the W/B ratios of 0.3, 0.4 and 0.5, respectively. The results indicated that the decrease in the W/B ratio (higher compressive strength) resulted in the increase of modulus of elasticity of concrete. This is due to that the modulus of elasticity of concrete was mainly controlled by the compressive strength which is obtained by decreasing the W/B ratio in the concrete mixture.

Fig. 13 presents the relationship between the value of modulus of elasticity and square root of the compressive strength for all concrete mixtures of this study, as compared to the modulus of elasticity values suggested by ACI 318 (2008). The modulus of elasticity of this study were higher than values of ACI 318 (2008) this may due to the modulus of elasticity and compressive strength of concrete suggested from ACI 318 (2008) were obtained from both of normal and lightweight aggregates. Morover, in this experiment, the results were obtained from cylinder specimen size of 100 mm in diameter and 200 mm in height, which was smaller than standard specimen (150 mm in diameter and 300 mm). The result indicates that the modulus of elasticity of BC and BC10 can be predicted using equation (3).

$$E_c = 5.31\sqrt{f_c'} \text{ --------------------- } (3)$$

When E_c and f_c' are modulus of elasticity (GPa) and compressive strength (MPa) of concrete, respectively.

Considering the relationship between the compressive strength and modulus of elasticity of BC concrete tends to be the same manner as that of CT concrete. For example, the modulus of elasticity of BC and BC10 concretes increased with the increased of the compressive strength. This result was similar to the concretes made from other pozzolanic materials mixed with calcium carbide residue to be used as a cementing material in concrete (Makaratat et al, 2010; Rattanashotinunt et al, 2013). This was due to the modulus elasticity of concrete depends on the strength of aggregate more than strength of paste (Neville, 1997). Khatri et al. (1995) and Hooton (1993) reported that the modulus of elasticity of concrete is principally a function of compressive strength. According to these results and the previous researches, it can be concluded that the use of BC and BC 10 as a cementing material in concrete did not affect on the modulus of elasticity when compared to CT concrete.

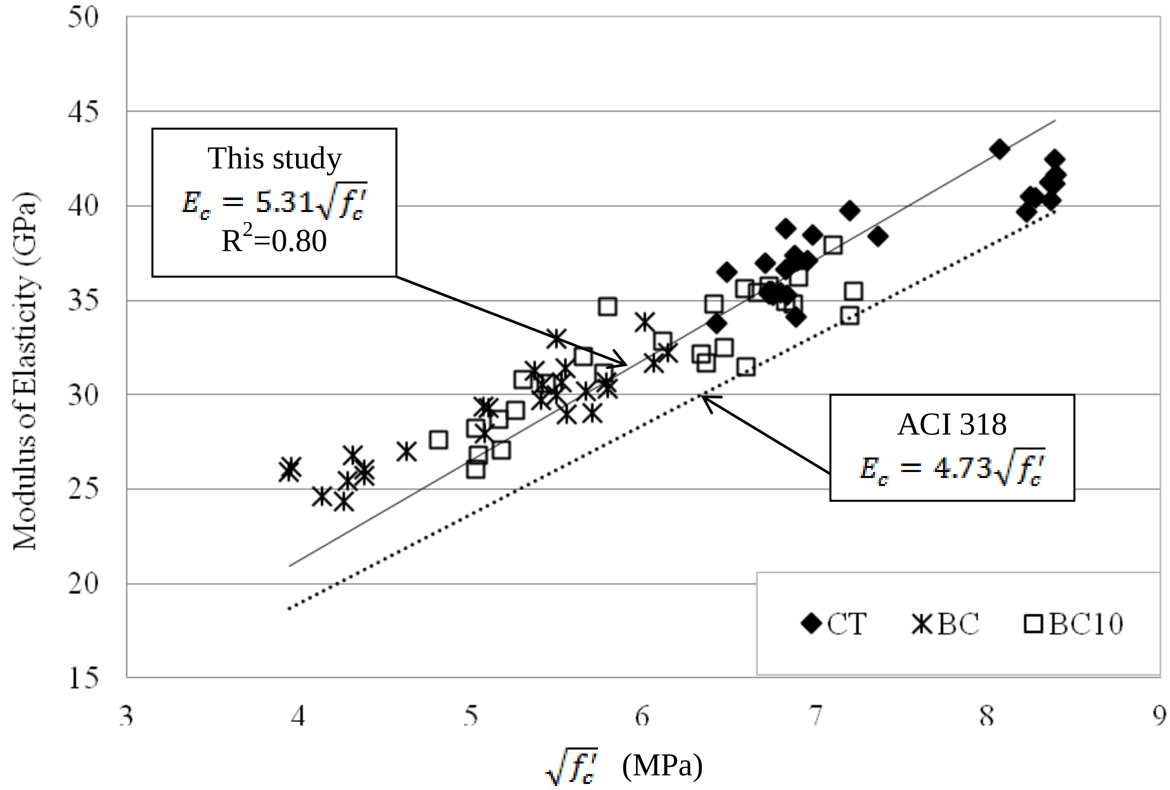

Fig. 13 Relationship between the modulus of elasticity and square root of the compressive strength of concrete

5.3 Utilization of calcium carbide residue and fly ash mixture as a binder in concrete block

5.3.1 Water Absorption of Concrete Paving Block

According to Table 7, 40GCF, 35GCF, 30GCF, and 35OCF concrete paving block had the water absorption at 146, 154, 195 and 222 kg/m^3 or equal to 7.04, 7.53, 10.21, and 12.47% by weight, respectively. It can be seen that the absorption of water depends on the density of sample that is while the density increases, the water absorption of concrete paving block drops. After comparing to the sampling binder which was ground and unground (35GCF and 35OCF), the block with grinding binder obviously had lower water absorption than the one without grounding. This is due to the fact that fineness of binder has a direct effect on the value of water absorption. The higher fineness of binder can increase the density of concrete paving block. It can be seen that when the concrete paving block has higher density; the porosity is reduced then the value of water absorption decreases. In addition, because of the smaller particles, a pozzolanic reaction between calcium carbide residue and fly ash can reduce the porosity of the cement gel (Chindaprasirt et al, 2007). As a result, the concrete paving block that use unground binder material which has higher porosity and lower value of density, has a higher value of water absorption than those using ground ones. Moreover, increasing pressure on forming of concrete paving block from 6 MPa to 8 MPa can make slightly increased the density, but the water absorption values are not different. Thus, it is indicated that water to binder ratio at 0.40 suitably to be used to increase the density of concrete paving block in order to lower the water absorption.

Table 5 Water absorption of concrete paving block

Blocks	Oven-Dry W./Volume (kg/m^3)	Absorption/Volume (kg/m^3)	Water Absorption (%)
40GCF	2073	146	7.04
35GCF	2044	154	7.53
30GCF	1914	195	10.21
40GCF8	2095	147	7.02
35GCF8	2044	158	7.73
30GCF8	2016	163	8.09
35OCF	1777	222	12.47

5.3.2 Compressive Strength of Concrete Block

According to Fig. 14, the results show that at the age of 7, 28, and 60 days, 35GCF concrete paving block with a ratio of W/B at 0.35 had the compressive strengths of 21, 36.6, and 42.4 MPa, respectively. This concrete paving block also provided the highest compressive strength because the pressure used during forming was quite high that increased the density in concrete, so that the porosity in concrete was reduced and the unwanted water was eliminated (Wattanasiriwech, 2009). Thus, the result of compressive strength of the 35GCF concrete paving block is consistent with Thai Industrial Standard TIS 827-2531 () that, at 28 days, the compressive strength of concrete paving block must higher than 35 MPa. On the other hand, 40GCF concrete paving block at W/B ratio of 0.40 had the compressive strengths of 20.5, 36.2, and 40.8 MPa at the age of 7, 28, and 60 days, respectively, which indicated some of too much water might be left after the reaction in concrete and decreased the compressive strength. Then, the lowest compressive strength was observed in 30GCF concrete paving block which had compressive strengths of 15.0, 26.5 and 29.6 MPa at 7, 28 and 60 days, respectively. This demonstrated that less water was used in the concrete mixture causing unequal compression and low density in the concrete paving block, so the compressive strength obtained was lower than those of the concrete paving block at W/B ratio of 0.35. Hence, the W/B ratio of 0.35 is considered as the most appropriate ratio for enabling the best compression in concrete paving block. This can be noted that too low value of W/B ratio causes insufficient water and in sufficient of compaction used for reaction in concrete paving block, whereas the density and the compressive strength in concrete paving block may be decreased because of the porosity caused by too high value of W/B ratio.

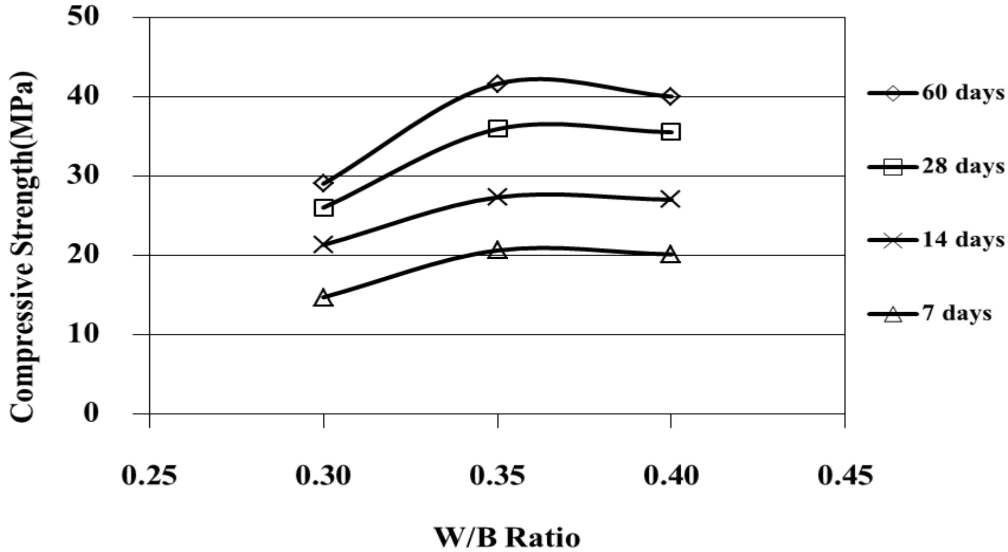

Fig. 14 Relationship between compressive strength and W/B ratio of concrete block

All in all, the development of compressive strength of 40GCF, 35GCF and 30GCF concrete paving block was increased by the increasing of curing age. Also, 40GCF and 35GCF concrete paving blocks developed compressive strength in a similar way because both of them approximately used an equal ratio of W/B at 0.40 and 0.35, respectively. However, during forming, some water came out from the concrete paving block at W/B ratio of 0.40 more than it does from the other using W/B ratio of 0.35. This made the rest of W/B ratio not different in the aspect of reaction. As a result, the compressive strength of the concrete paving block using W/B ratio of 0.35 and 0.40 was not different. Conversely, the different result was shown by observing the compressive strength of the 30GCF concrete paving block using W/B ratio of 0.30 that caused a dry concrete mixture. This led to a low compressive strength and low density in the concrete paving block. Also, the compressive strength gained was lower comparing to those of the concrete paving block at W/B ratio of 0.40 and 0.35.

According to Table 6, which shows the compressive strength of the concrete paving block, at the age of 28 days 40GCF, 35GCF, 40GCF8 and 30GCF8 had the compressive strength of 36.2, 36.6, 36.9 and 35.6 MPa respectively. Only 35GCF8 concrete paving block has the compressive strength more than 40 MPa. However, it is still higher than the minimum standard of ASTM C1319 (2014) which defines the compressive strength not less than 35 MPa. This can be concluded that these sample of concretes paving blocks pass the minimum requirement in compressive strength defined by ASTM C 1319 (2014).

Table 6 Compressive Strength of concrete paving block

Blocks	Compressive Strength (MPa)-***(Percentage Compressive Strength)***			
	7 days	14 days	28 days	60 days
*TIS-827	40.0-***(100)***	40.0-***(100)***	40.0-***(100)***	40.0-***(100)***
45OCF	9.3-***(23)***	17.0-***(43)***	21.3-***(53)***	27.6-***(69)***
40OCF	11.8-***(30)***	17.5-***(44)***	22.3-***(56)***	28.8-***(72)***
35OCF	9.0-***(23)***	14.2-***(36)***	18.7-***(47)***	23.6-***(59)***
40GCF	20.5-***(51)***	27.5-***(69)***	36.2-***(91)***	40.8-***(102)***
35GCF	21.0-***(53)***	27.8-***(70)***	36.6-***(92)***	42.4-***(106)***
30GCF	15.0-***(38)***	21.7-***(54)***	26.5-***(66)***	29.6-***(74)***
40GCF8	20.3-***(51)***	27.9-***(70)***	36.9-***(92)***	41.8-***(105)***
35GCF8	21.2-***(53)***	33.6-***(84)***	41.4-***(104)***	45.3-***(113)***
30GCF8	20.9-***(52)***	26.6-***(67)***	35.6-***(89)***	43.7-***(109)***

From Fig. 15, the results reveal that the unground concrete paving block (35OCF), at the age of 7, 28, and 60 days, had the compressive strengths of 9.0, 18.7 and 23.6 MPa, respectively. On the other hand, the concrete paving block (35GCF) which was mixed with ground calcium carbide residue-fly ash had compressive strengths of 21.0, 36.6 and 42.4 MPa which obviously higher than the former one. This showed that the fineness of binder affected directly on the compressive strength of the concrete paving block. At 60 days, 35GCF concrete paving block had the compressive strength of 42.4 MPa, while that of 35OCF concrete paving block merely had the compressive strength of 23.6 MPa which was much lower than the previous one about 1.8 times. Since the unground calcium carbide residue and fly ash had bigger particles, the reaction of the two materials slow and thus gave the low compressive strength. This result supports the previous research of Sata et al. (2007) that grinding can enhance the compressive strength of concrete containing pozzolan. However, according to Thai Industrial Standard TIS 59 (1973), the unground calcium carbide residue-fly ash can be used for Grade B concrete production as well.

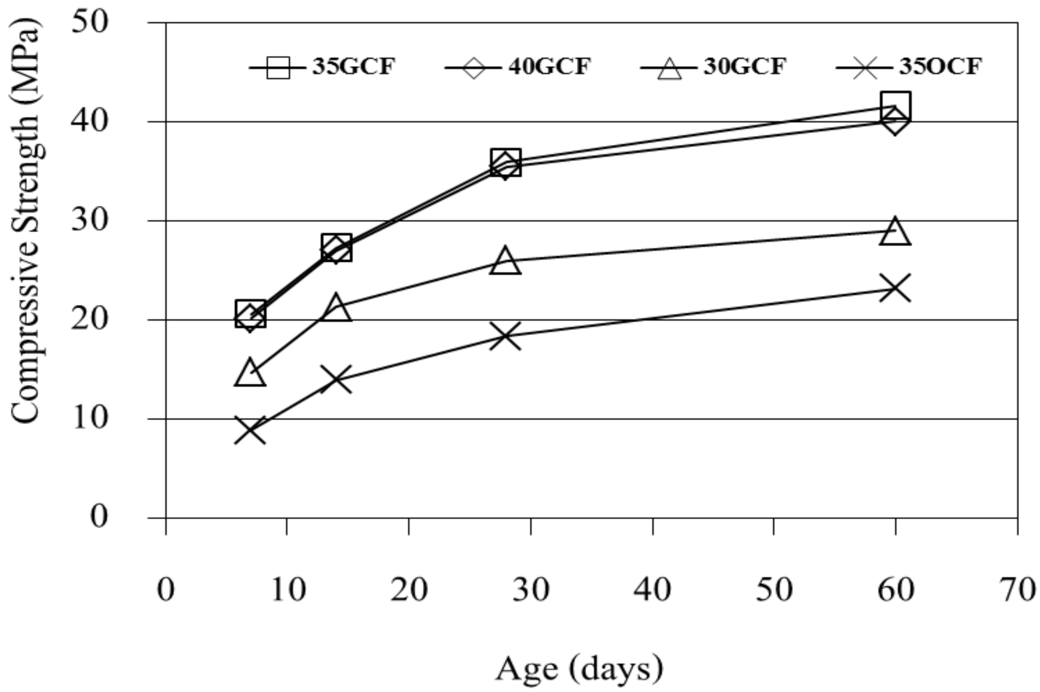

Fig.15 Relationship between compressive strength and age of concrete paving block

5.4 Utilization of calcium carbide residue and bottom ash mixture as a binder in concrete block

5.4.1 Water Absorption of Concrete Paving Block

The dry density and water absorption of concrete block at 28 days were shown in Table 7 .It was found that the GCB concrete blocks had dry density of 1948, 2021, and 2075 kg/m^3, with w/b ratios of 0.30, 0.27 and 0.25, respectively. While the dry density of OCB concrete blocks were 1802, 1792, and 1769 kg/m^3, with w/b ratios of 0.55, 0.45 and 0.40, respectively. This result indicated that, the finer of GCB binder leading to increased higher dry density of concrete block than OCB binder. This due to the specific gravity of GCB binder had 2.39, which was higher than the specific gravity of OCB binder. In addition the finer of GCB binder could be filled the porosity in paste of concrete block by packing effect (Chindaprasirt et al, 2005) and increased pozzolanic product better than OCB binder, leading to increase of dry density. In fact, the total pore in concrete blocks was decreased with decrease w/b ratio (Ngala and Page, 1997; Lo et al, 2007; Živica, 2009) thus, the lower w/b ratios mixtures of GCB concrete blocks may cause to less porosity than OCB concrete block, resulting in also increase of its dry density.

Table 7 Dry density and water absorption of concrete block at 28 days

Concrete blocks	Oven-Dry W./Volume (kg/m^3)	Water Absorption (%)
30GCB	1948	9.6
27GCB	2021	7
25GCB	2075	6.3
55OCB	1802	13.6
45OCB	1792	14.8
40OCB	1769	16

When the dry density of GCB concrete block was considered with w/b ratio. It found that the decrease w/b ratio resulted in slightly increased dry density. As mentioned above, the lower w/b in concrete block mixture could reduce total pore paste, resulting in increased density of concrete block. However in case of OCB concrete block found that, when decrease w/b ratio resulted in slightly decreased dry density. This because the higher w/b ratio of OCB mixture remained more free water than the lower w/b ratio in mixture, this due to the water was absorbed by higher porosity of OBA particle. The lesser of free water in mixture caused to reduce efficiency of pozzolanic reaction, resulting in the increase voids volume in paste matrix.

The water absorption GCB concrete block ranged from 6.3 to 9.6 %. While OCB concrete block had the water absorption ranged from 13.6 to 16.0 %. This result suggested that the OCB concrete absorbed more water than GCB concrete block. It was clearly the higher porosity of OBA in OCB binder had been affected to the absorption of concrete block rather than GCB binder. In addition the denser in paste matrix of pozzolonic product in OCB concrete block was reduced due to the larger of its particle compared with GCB, causing to large amount of voids in paste matrix and high water absorbed to concrete block. Moreover the higher fineness particle size of GCB binder could easily fill up the voids between the aggregates, hence increasing the density of and reducing water absorption of concrete block (Poon and Lam, 2008).

5.4.2 Compressive Strength of Concrete Paving Block

The mainly growth of GCB and OCB compressive strength was obtained by pozzolanic reaction between calcium hydroxide from calcium carbide residue reacted with siliceous or siliceous and aluminous materials from bagasse ash produce the calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) product, which is usually much slower than the hydration reaction of Portland cement (Rattanashotinunt et al, 2013). Table 8 shows the compressive strength and percentage of compressive strength of the GCB and OCB concrete blocks as compared to compressive strength requirement specified by TIS 827 (1988) standard at each testing days. The compressive strength of GCB concrete blocks raged from 23.6 to 27.2 MPa at 7 days, increase to rage from 32.5 to 40.6 MPa and 36.7 to 47.3 MPa at 28 and 60 days, respectively. While the OCB concrete block had compressive strength raged from 6.9 to 11.2 MPa at 7 days and increase to rage from 12.2 to 16.9 MPa and 14.6 to 19.7 MPa at 28 and 60 days, respectively. These results suggested that, the fineness particle had more affected on the increasing of concrete block compressive strength with three main reasons. Firstly the lager particle of OCB binder required more water content in concrete block mixture, due to its particle had high porosity (OBA particle) and rough surfaces (OBA and OCR particles). Thus the compressive strength of OCB concrete block was lower than GCB concrete block because of the increasing of w/b ratio in concrete block mixture. Secondly the finer particle size of GCB binder with a higher surface area could improve the pozzolanic reaction. This result supported that of Chusilp et al. (2009), they reported the GBA had particle retained on a sieve no. 325 less than of 5% could accelerate the pozzolanic reaction and improve the compressive strength of concrete. Finally the void or air space in concrete block structure was filled by smaller particle of GBA to produces dense concrete, resulting in an increase of its compressive strength by packing effect, especially at an early ages (Isaia et al, 2003; Tangpagasit et al, 2005).

Fig. 16 and Fig. 17 show relationship between compressive strength and w/b ratios of GCB and OCB concrete block, respectively. The results showed that the compressive strength of GCB concrete block was increased with decrease the w/b ratios. These results indicated that the fineness of GCB binder could reduce w/b ratio in concrete block mixture to obtained higher compressive strength in a way of normal concrete [23-25]. While the compressive strength of OCB concrete block was increased with increase the w/b ratios, which tend to opposite result of GCB concrete block. This result suggested that the sufficient water content is major parameter in process of pozzolanic reaction. The lesser water content of OCB concrete block at lower w/b ratio is not enough to complete the pozzolanic reaction. This due to the OCB binder was higher porosity and irregular shapes, resulting in higher water absorption of OCB binder and increase water demand in concrete block mixture.

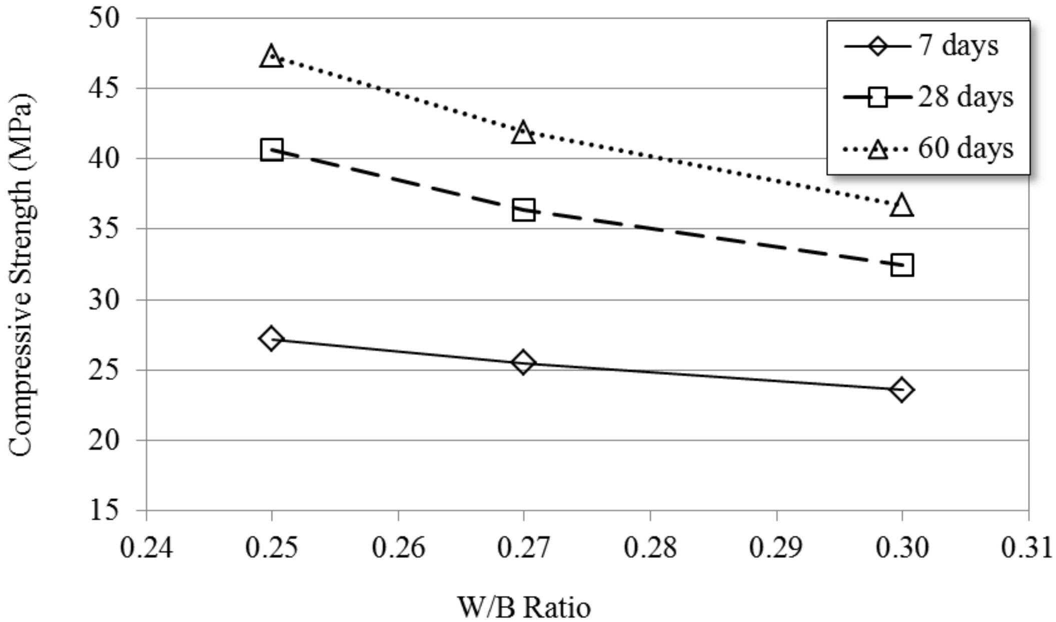

Fig. 16 Relationship between the compressive strength and W/B ratio of GCB concrete blocks

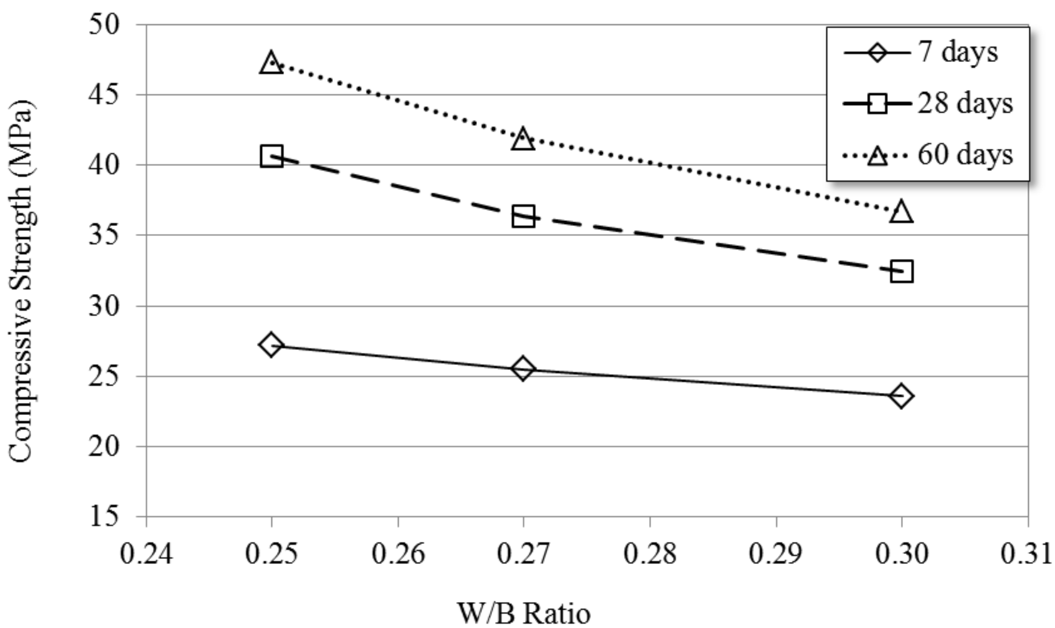

Fig. 17 Relationship between the compressive strength and W/B ratio of OCB concrete blocks

The relationship between compressive strength and dry density of both GCB and OCB concrete blocks is polynomial line, as can be seen in Fig 17. As expected, the increased in density resulted in increasing compressive strength of concrete blocks and the relationship between compressive strength and dry density of the GCB concrete block tends similar to OCB concrete blocks. The GCB concrete block had compressive strength of 32.5, 36.4 and 40.6 MPa with dry density of 1948, 2021 and 2075 kg/m^3, respectively. While the lower compressive strength of OCB concrete block were 12.2, 14.5 and 16.9 with dry density of 1769, 1792 and 1802 kg/m^3, respectively. The results indicated that, dry density of concrete block is one of the factors on the increasing of its compressive strength (i.e. the compressive is dependent factor while dry density is independent factor). The result also agreed with that of Ling (2012), who reported that the compressive strength of rubberized concrete paving block was increased with increase the its density. Poon and Chan reported that (Poon and Chan, 2007) the a compressive strength trend of the paving blocks prepared with recycled concrete aggregates increased with an increase in density concrete paving block.

Considering the results compare with TIS 827 standard (1988). It found that two mixtures of concrete blocks were 27GCB concrete block had compressive strength 41.9 MPa at 60 days and 25GCB concrete block had 40.6 and 47.3 MPa at 28 and 60 days respectively, which their compressive strength were greater than the minimum requirement for concrete paving block of 40.0 MPa specified by TIS 827 standard (1988). The results indicated that the use of three kind waste materials, calcium carbide residue, bagasse ash and recycled aggregate, could be produced concrete block for paving accordance with TIS 827 standard (1988). The use of these waste materials to produce concrete block not only to reduces the quantity of waste in landfill, but also reduce of Portland cement usage and natural aggregate, resulting in reduction of CO_2 emissions which that is good for the environment. In addition, calcium carbide residue, bagasse ash and recycled aggregate are by-products, their cost is zero. The major cost of CR and BA depend on the grinding process of reducing their particle for obtains higher compressive strength, resulting in cheaper than using Portland cement as a binder.

6. Conclusions

Based on these results, the following conclusions can be drawn:

6.1. Concretes Made from Calcium carbide residue and Fly Ash mixture

1. All of the activation methods could be used to enhance the strength of concrete made from CCR and FA mixture, with the increase the fineness of a new cementing material being the most effective method. The compressive strength of concrete activated by this method could be as high as 55.0 MPa at 28 days and increased up to 66.1 MPa at 90 days.

2. Concrete made from the mixture of CCR and FA as a cementitious material had the characteristic of modulus of elasticity similar to the concrete produced by Portland cement and all activation methods had no significant effects on elastic modulus, which were related to concrete compressive strength.

3. The chloride resistance of concrete in terms of chloride ion penetration and corrosion of reinforcing steel in concrete could be considerably improved by all activation methods. All of the concrete mixtures using CCR and FA as a binder with and without activated strength significantly improved the resistance of chloride ion penetration of concrete, with the total change passed of the concretes being lower than 400 coulombs.

4. Among the activated strength methods, physical and chemical activation (OFC-C and FFC) could reduce the corrosion of reinforcing steel in concrete, with the weight loss of the reinforcing steel being lower than that of ordinary Portland cement concrete.

5. Concrete made from CCR and FA mixture had possibility to use as a low heat concrete, the heat evolution of CCR and FA mixture was much lower than that the concrete produced by OPC. All of CCR-FA concretes could be reduce the peak temperature rise of concrete about 30-36 °C of OPC concrete.

6.2. Concretes Made from Calcium carbide residue and Bottom Ash mixture

1. The use of BC as a cementing material content of 550 kg/m3 in concrete without OPC could produce the compressive strength of 29.7 MPa at 28 days, which is similar to conventional concrete with a cement content of 300 kg/m3. In addition, the partial replacement 10% of OPC by weight in BC10 concrete with W/B ratio of 0.3 could develop the compressive strengths to be as high as 44.3 and 51.4 MPa at 28 and 90 days, respectively.

2. BC concretes with W/B ratios of 0.3 and 0.4 had the compressive strengths higher than the minimum requirement for structural concrete member of 17.2 MPa (2500 psi) specified by ACI 318 at 28 days. However, for BC concrete with W/B ratio of 0.5, a OPC of 38 kg/m3 is required to produce the compressive strength of 24.6 MPa at 28 days.

3. The concrete properties in term of modulus of elasticity of BC or BC10 concretes did not differ from CT concrete, because those properties are depended mainly on the compressive strength of concrete and the strength of aggregate.

6.3. Utilization of calcium carbide residue and fly ash mixture as a binder in concrete block

4.1 The concrete paving block used mixed calcium carbide residue-fly ash as a binder and used aggregate obtained from recycled aggregate could be used as raw materials to produce concrete paving block without Portland cement, which was friendly to the environment and also turned the waste into value-added material. The compressive strength of the paving blocks was increased by the increasing of curing age. In addition, grinding the binder obviously increased the compressive strength of the concrete paving block.

4.2 The concrete paving block using a mixture of ground calcium carbide residue-fly ash as a binder and recycled crushed concrete as a fine aggregate with a pressure of 6 and 8 MPa could increase the compressive strength from 42.4 MPa to 45.3 MPa. The values were higher than those proposed by ASTM C1319 (not less than 31 MPa).

4.3 The concrete paving block using a mixture of unground material as a binder could also be used as a raw material for concrete production, but those materials were categorized as Grade B according to Thai Industrial Standard TSI 59.

4.4 The water absorption of the concrete paving block was about 7-13%. This value was inversely related to the density in the concrete paving block.

6.4. Utilization of calcium carbide residue and bottom ash mixture as a binder in concrete block

1. The properties of concrete block made from a binder of CR and BA and RA as an aggregate could be developed by increase the fineness of binder and reduce w/b ratio in GCB concrete block mixture.

2. The using of OCB binder in concrete blocks causes to absorb more water than using GCB binder in concrete block mixture.

3. The compressive strength of concrete block was increased with increase its dry density.

4. The compressive strength of GCB concrete block was increased with decrease the w/b, on the other hand, the decreased of w/b ratio caused to reduce compressive strength of OCB concrete.

7. Suggestions

Based on the results from this study, the following suggestions are offered for future investigation:

From this study, the mixtures of calcium carbide residue and fly ash or bottom ash concretes could be used as new cementing materials in concrete and concrete block. Therefore, the other properties in actual work should be studied such as the carbonation, creep, and other chemical attacks determined by immersing the specimens in sea water or waste water.

The results from this experimental study concluded that the fineness of calcium carbide residue, fly ash, and bottom ash is one of the major factors to increase the compressive strength and other properties of concrete and grinding process could increase theirs fineness. Therefore, grinding method and grinding machine should be studied to reduce the grinding cost.

8. Acknowledgements

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10. Output

International Publications

1. Saofee Dueramaea, Weerachart Tangchirapata, Prinya Chindaprasirt, and Chai Jaturapitakkul. Influence of activation on strength and chloride resistance of concrete using calcium carbide residue - fly ash mixture as a new binder, submitted to Journal of Materials in Civil Engineering (ASCE). Under Review.
2. Akkadath Abdulmatin, Penpicha Khongpermgoson, Weerachart Tangchirapat, and Chai Jaturapitakkul. Development of Bottom Ash as a Cementing material with Little or Without Portland Cement for Environmental Friendly Concrete, Submitted to Journal of Materials and Design. Under Review.