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Original Research Paper

Strength and heat generation of concrete using carbide lime and fly ash as a new cementitious material without Portland cement

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ABSTRACT

The aim of this paper is to investigate mechanical properties and heat generation of concrete produced with a carbide lime (CL) and fly ash (FA) mixture as a new cementitious material without Portland cement. Two techniques were used to improve the strength of concrete: adding of NaOH into the new binder (1% by weight) and increasing the fineness of new binder. Microstructural mechanism in term of SEM microscopy, EDX analysis, and XRD patterns of CL-FA pastes were examined. The following properties of cement-free concrete were also examined: heat generation, compressive strength, elastic modulus, and splitting tensile strength. The results of microstructural revealed that the products of binder made from CL and FA were C-S-H and C-A-S-H phase types and the formations of C-S-H and/or C-A-S-H were attributed to components of Al, Si, and Ca. The results also showed that the peak temperature rise of concrete made from CL and FA could be reduced by 30–36 °C from that of the OPC concrete. Regarding the mechanical properties of concrete, the technique of improving strength by increasing the fineness of new cementing material was the best method and could produce the 28-day compressive strength of 55.0 MPa. CL-FA concrete had elastic modulus and tensile strength similar to those of OPC concrete. Furthermore, the techniques to improve the strength of concrete had no significant effect on the elastic modulus and tensile strength of concrete since those properties were related to the compressive strength of concrete. Moreover, the concrete had a very low heat generation as compared to the OPC concrete.

1. Introduction

The cement hydration process introduces a large amount of heat generation at an early age. The higher rate of heat generation is caused by hydration processing of Portland cement which depends on the C_3S and C_3A contents and the hydration of Portland cement releases heat up to 500 J/g [1,2]. The heat generation of concrete is significant high dependent on the quantity of cement, particularly for mass concrete. The large size specimen of mass concrete gave a high temperature rise leading to a large difference in temperature between the interior and the concrete surface. The difference in temperature of the inner region and the surface of concrete is very dangerous regarding the integrity of concrete because cracks may form via thermal stress, if the different of the temperature is higher than 20 °C [3,4]. In addition, the initial temperature of concrete above 70 °C could produce an effect of delayed ettringite formation (DEF) and caused the expansion from ettringite, resulting in crack formation at later ages [5]. Moreover, the Portland cement manufacturing process has many undesirable effects to the environment because Portland cement process requires a large amount of energy to burn raw materials, thereby releasing a high amount of CO_2 gas into the atmosphere, i.e., approximately 0.9 ton per 1 ton of cement or 90% by weight of Portland cement production [6].

To reduce the heat generation of concrete, many methods were used to control the temperatures of concrete, such as the pre-cooling material of concrete before mixing (cement, aggregates, and water), and the post cooling system with embedded water pipe into concrete [7–9]. However, the use of pre- and post-cooling techniques is expensive, more difficult to implement, and complicated for the construction process. Many researchers use supplementary cementitious materials for reducing the temperature rise of concrete; they are fly ash [10], bagasse ash [11], and palm oil fuel ash [12]. However, concretes containing various pozzolanic materials must require a part of Portland cement to be in the mixture. Previous research studies demonstrated that a new cementitious material made from carbide lime (CL) and fly ash (FA) can be used for making concrete without Portland cement [13,14].

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CL is a by-product waste from acetylene gas production. The primary chemical composition of CL is $Ca(OH)_2$ which could be dissolved in water. The high $Ca(OH)_2$ content of CL can react with SiO_2 and AlO_3 from fly ash to produce C-S-H and C-A-S-H gels, thereby providing a strength similar to the cement hydration process [15]. As suggested by previous study of Krammart et al. [13] the optimal ratio between CL and FA as a binder was 30:70 by weight to produce the maximum compressive strength of mortar. Note that the mixture made from 30% CL and 70% FA could be utilized as a new concrete binder without Portland cement. However, the development of the compressive strength of the concrete was slow, particularly below 7 days [13,14]. In addition, the concrete made from CL and FA as a new cementing material is not well-known; thus additional knowledge is required to build confidence in the used of this new material.

The goal of this research is to study the possibility to produce low heat concrete made from CL and FA without Portland cement and to determine the mechanical properties of such concrete. Two techniques to promote strength of CL-FA concrete were used in this study, which were adding 1% of NaOH by weight of binder and increasing the fineness of binder. The heat generation and mechanical properties namely, compressive strength, modulus of elasticity, and splitting tensile strength of cement-free concrete made from a new cementitious material were examined and compared to the properties of OPC concrete.

2. Experimental investigation

2.1. Materials

The FA used in this study was collected from a thermal power plant in the northern part of Thailand, from which lignite coal was burnt in the pulverized combustion process. Table 1 gives the chemical compositions of FA and CL. The oxide contents of SiO_2, Fe_2O_3, and Al_2O_3 are 41.9%, 21.5% and 12.7%, respectively. The FA can be categorized as a class F fly ash as specified by ASTM C618 [16], because the total of SiO_2, Fe_2O_3, Al_2O_3 was of 76.1%, which was higher than 70%.

CL was acquired from an acetylene gas creation manufacturer at Samutsakorn province, Thailand. The primary chemical component of CL was 56.5% of CaO. Moreover, the LOI of CL was very high at 36.1% wt. because CL mainly consists of $Ca(OH)_2$. The high value LOI in CL was due to $Ca(OH)_2$ disintegrating into CaO and H_2O (gas) at a temperature of approximately 550 °C, while the LOI was determined at the temperature of 750 ± 50 °C [17].

CL and FA were mixed together at a ratio of 30:70 by weight as recommended by the previous investigation [13]; this ratio produced the highest compressive strength of mortar. According to Table 2, the unmodified CL and FA mixture (designated as UCF) had particles retained on a sieve No. 325 of 22.9% wt. and had a median particle size of 12.92 μm. After grinding, the particles of modified CL and FA mixture (designated as MCF) were smaller, which had particles retained on a sieve No. 325 of 1.1% wt., with the median particle size being reduced to 2.93 μm. Moreover, the density of unmodified CL-FA was 2.43 g/cm^3 and was increased to 2.73 g/cm^3 after grinding to increase the fineness (modified CL - FA). The maximum size and density of coarse aggregate was 19.0 mm and 2.72 g/cm^3, respectively. The fine aggregate had a density of 2.62 g/cm^3.

Table 2
Physical property of the materials.

Material	Density (g/cm^3)	Retained on a Sieve No.325 (%)	Median Particle Size: d_{50} (micron)
Cement (OPC)	3.15	20.0	14.60
Unmodified CL-FA (UCF)	2.43	22.9	12.92
Modified CL-FA (MCF)	2.73	1.1	2.93

2.2. Mix proportion of mortar

To investigate the optimum amount of NaOH to increase the strength of the binder from CL and FA as a binder, the addition of NaOH solution in this study was varied as 0%, 0.5%, 1%, 2% and 3% by weight of binder. Standard mortar in the form of 5 cm cubical specimens was used to investigate the compressive strength from which the average of five specimens was used. The mix proportions of mortars are summarized in Table 3. All mortars had a w/b ratio of 0.29 and superplasticizer was used to control the mortar flow between 105 and 115. After casting for 24 h, the mortar specimens were demolded, and then submerged in tap water until the testing ages of 3, 7 and 28 days.

2.3. Mix proportion of concrete

In this experimental, a new cementitious material was developed to produce concrete without Portland cement, i.e., CL mixed with FA at a ratio of 30:70 by weight (UCF). CL-FA concretes had a binder of 550 kg/m^3 compared to concrete made from OPC, which had a binder of 500 kg/m^3. The w/b ratio was held as a constant at 0.25 and superplasticizer was used to obtain the concrete slump between 150 and 200 mm. In this examination, two techniques were used to enhance the strength of concrete made from CL and FA as a binder: (1) adding 1% of NaOH by weight of binder (designated as UCF-1N); (2) increasing the fineness of binder by grinding CL and FA together until the particles of the mixture retained on a sieve No. 325 were less than 1.1% wt. (designated as MCF). All concretes were demolded after casting for 24 h and then submerged in tap water until the date of testing. The mixture proportions of concretes using CL and FA as a new binder are given in Table 4.

Table 1
Chemical compositions of the materials.

Chemical Composition (%)	Cement (OPC)	FA	CL	MCF
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	0.5
Magnesium Oxide (MgO)	1.3	2.6	1.7	1.9
Sodium Oxide (Na_2O)	0.3	2.7	–	2.1
Potassium Oxide (K_2O)	0.4	2.5	–	1.7
Loss on Ignition (LOI)	0.9	0.7	36.1	10.1

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