USING FLY ASH, PALM OIL FUEL ASH, AND SUGARCANE BAGASSE ASH AS DENSITY AND COMPRESSIVE STRENGTH ADDITIVES FOR API CLASS G CEMENT

Watcharakon Setwong* **and Akkhapun Wannakomol**

Received: March 01, 2017; Revised: May 19, 2017; Accepted: June 16, 2017

Abstract

The main objective of this research was to study the density and compressive strength behavior of API class G cement when it was mixed with selected pozzolanic materials including fly ash, palm oil fuel ash, and sugarcane bagasse ash. Each selected pozzolanic material was mixed with cement slurry by varying the weight of the binder material (wt.%), then it was tested for the density and compressive strength properties according to the API Standard at room temperature and 80°C. The study's results reveal that the optimum cement mixed ratio is 20% by weight of binder material for all the selected pozzolanic materials, since the value of the compressive strength and density of the cement slurry were appropriate. Furthermore, the compressive strength of cement mixed with fly ash was higher than cement mixed with sugarcane bagasse ash and palm oil fuel ash, respectively.

Keywords: API class G cement, density, compressive strength, fly ash, palm oil fuel ash, sugarcane bagasse ash

Introduction

In many parts of the world, lost circulation and weak formations with low fracture gradients are common. These situations usually require a low-density cement system to reduce the hydrostatic pressure of the fluid column during cement placement. Consequently, lightweight additives (also known as extenders), are used to reduce the weight of the cement slurry (Mitchell, 2006) in order to avoid a rock formation from breaking down while cementing in subnormal pressure conditions.

In order to lighten and increase the cement's compressive strength, some pozzolanic materials can be used as an additive for these purposes. Recently, the civil construction industry has applied pozzolanic materials such as fly ash, palm oil fuel ash, and sugarcane bagasse ash as cement additives to improve cement's properties. Pozzolanic cements are typically used to produce lightweight slurries because the specific gravity of the pozzolanic material is lower than that of the cement (Chindaprasirt *et al*., 2009).

Pozzolanic material is a fine aggregate mass which is added to cement in order to increase the concrete's compressive strength at the age of more than 3 months (Berry and

School of Geotechnology, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima, 30000 Thailand. Tel. 0-4422-4441; E-mail: watcharakon.set@gmail.com

* *Corresponding author*

Malhotra, 1980; Naik and Singh, 1995). Some pozzolanic materials also have a high water demand that effectively gives a higher yield and a lighter slurry. They also tend to improve the compressive strength over time. In most cases, it has been explained that pozzolanic materials can also reduce the effect of sulfate attack based on the slurry's design (Chindaprasirt *et al.*, 2007), but the appropriate mixing ratio of the cement, pozzolanic material, and other binder materials has not been well studied and determined.

A pozzolan is a material that is made up of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and ferric oxide (Fe_2O_3) as the main components and, when the oxides of these 3 are combined, it will not be lower than 50% of the total mass of water; there may be little or no binder, but after the milling process it can react with calcium hydroxide ($Ca(OH)_2$) which is a product from the hydration reaction. The hydration reaction is the reaction of cement when it reacts with water. This reaction produces the compound of calcium silicate hydrate (C-S-H), calcium aluminate hydrate (C-A-H), ettringite, and calcium hydroxide ($Ca(OH)_2$). $Ca(OH)_2$ from the hydration reaction also reacts with SiO_2 and Al_2O_3 in pozzolanic material and provides a compound of C-S-H and C-A-H), respectively. These 2 reactions are called the pozzolanic reaction. However, the pozzolanic reaction is limited by the amount of SiO_2, Al_2O_3, and $Ca(OH)_2$ from the hydration reaction of the cement (Serametjakun, 2001).

However, in the petroleum industry, there are very few areas of study using pozzolanic materials as cement additives. Only the well-known micro fly ash cement component helps control strength retrogression and this component exhibits a superior compressive strength (Halliburton Company, 2003). That is a high-cost additive in the oil-well cement industry. Therefore, this study aims to determine the optimum pozzolanic material mixing ratio in order to improve the strength of the mixed cement slurry samples. Some local and abundant pozzolanic materials, fly ash, sugarcane bagasse ash, and palm oil fuel ash, were used in this study since they are waste products, low-cost, and easy to procure locally.

Materials and Methods

Materials

API class G cement (CMCG), intended for use as basic cement from the surface to a depth of 2500 meters as manufactured, was selected for the experiments in this study. The selected pozzolanic materials, fly ash (FLYA), palm oil fuel ash (POFA), and sugarcane bagasse ash (SCBA) were ground by ball mill and sieved through a sieve No. 325 to get the size of the particles smaller than 45 microns. The physical properties and chemical compositions of these materials are shown in Tables 1 and 2, respectively. The particle size distribution curve of the CMCG and pozzolanic materials, using a laser diffraction particle size distribution analyzer, are shown in Figure 1. The mean particle size of the FLYA was 12.75 microns, which was larger than the CMCG (10.77 microns). The mean particle sizes of the POFA and SCBA were 25.29 and 19.83 microns, respectively.

The particle shapes of the CMCG and pozzolanic materials are presented in Figure 2. The particle shape of the FLYA is spherical with a smooth surface indicating a rather complete burning. The particle of the POFA is rather spherical and a little angular and irregular in

Table 1. Materials' properties

Materials	Specific gravity (SG)	Color	Particle size (µm)
CMCG	3.19	Dark grey	< 45
FLYA	2.54	Brown	< 45
POFA	2.27	Light grey	< 45
SCBA	2.08	Black	< 45

Note: CMCG = API class G cement, FLYA= Fly ash, POFA = Palm oil fuel ash, SCBA = Sugarcane bagasse ash

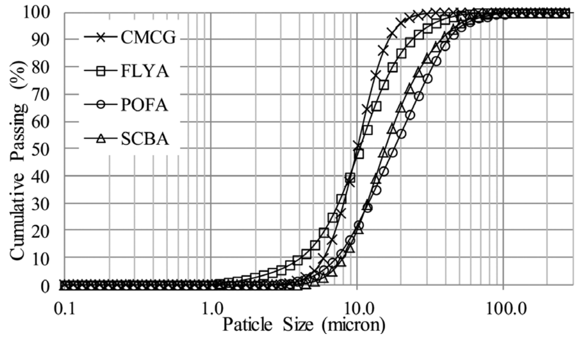


Figure 1. Particle size distribution of materials

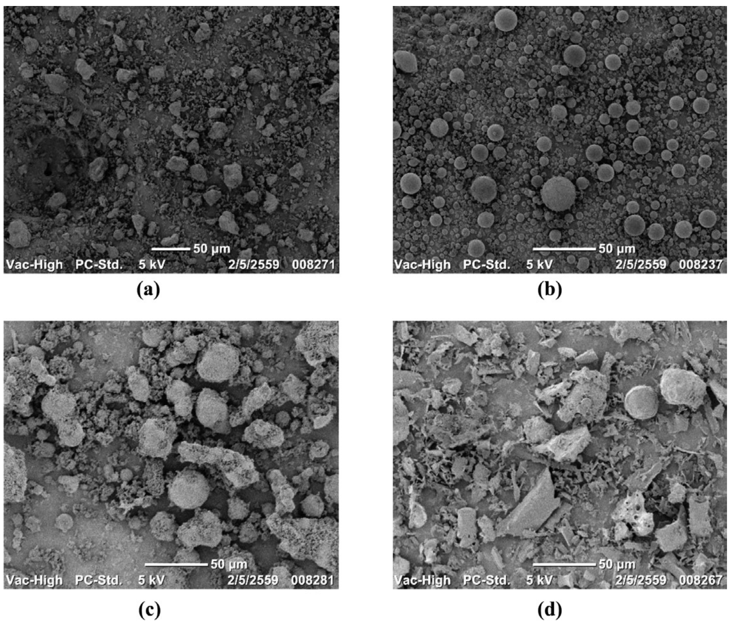


Figure 2. Scanning electron microscope (SEM) images of materials: (a) = CMCG, (b) = FLYA, (c) = POFA, (d) = SCBA

Table 2. Chemical composition of cement and pozzolanic materials

Compounds	Chemical composition (wt.%)			
	CMCG	FLYA	POFA	SCBA
MgO	1.96	1.60	5.84	2.45
Al_2O_3	1.21	5.07	0.38	3.60
SiO_2	4.49	10.73	17.07	44.85
SO3	0.55	0.59	4.21	0.08
K_2O	0.27	2.63	38.81	6.30
CaO	86.61	28.40	23.78	11.53
TiO_2	0.29	0.04	0.40	2.69
Fe_2O_3	4.46	50.43	8.61	27.46
MnO_2	0.15	0.51	0.90	1.04

shape, and the POFA had little porosity on the particle's surface. On the other hand, the SCBA had an angular and irregular particle shape which was similar to the CMCG, but it had much more porosity on the particle's surface.

Cement Mixtures

The CMCG was partially mixed with the FLYA, POFA, and SCBA at 10%, 15%, 20%, and 30% by weight of the binder material. The amounts of the selected pozzolanic materials and mixing water for all cement mixtures are shown in Table 3.

Cement Slurry and Concrete Test

In this study, the densities of the cement slurry samples were increased, while the concrete samples made from these cement slurries were also measured for their compressive strength.

i) Cement slurry density measurement

The densities of the cement slurry containing the FLYA, POFA, and SCBA at 10%, 15%, 20%, and 30% by weight of the binder material were measured at room temperature and at 80°C using a fluid density balance cup, as shown in Figure 3.

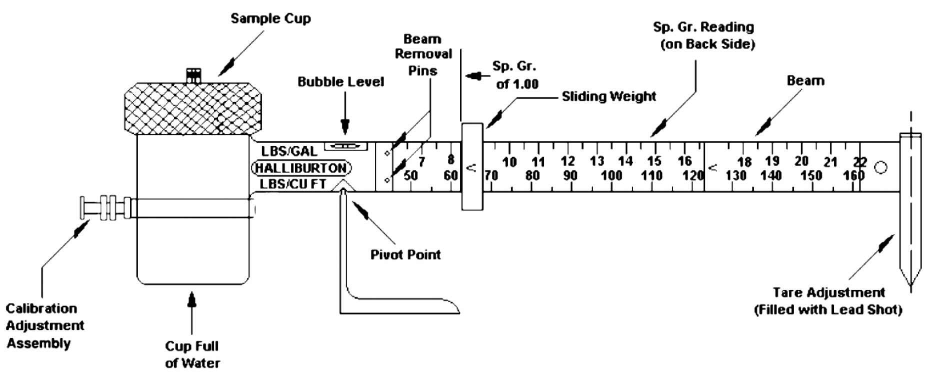


Figure 3. Fluid density balance cup

Table 3. Cement slurry compositions

Mixtures	CMCG (gm)	FLYA (gm)	POFA (gm)	SCBA (gm)	Water (ml)	W/B
CMCG	1500				750	0.500
FLYA10	1350	150			750	0.500
FLYA15	1275	225			750	0.500
FLYA20	1200	300			750	0.500
FLYA30	1050	450			750	0.500
POFA10	1350		150		750	0.500
POFA15	1275		225		750	0.500
POFA20	1200		300		750	0.500
POFA30	1050		450		750	0.500
SCBA10	1350			150	750	0.500
SCBA15	1275			225	750	0.500
SCBA20	1200			300	750	0.500
SCBA30	1050			450	750	0.500

Note: W/B=Water and Binder material ratio

ii) Concrete compressive strength measurement

The cement slurry samples were poured into molds measuring 2×2×2 inches, cast, and cured in water at room temperature and at 80°C until they reached the testing ages of 7, 28, and 50 days. Figure 4 depicts 1 of the study's concrete samples. The compressive strengths of the concrete samples were then determined using a compressive strength testing machine at the Civil Engineering Laboratory of Suranaree University of Technology (SUT).

Results and Discussion

Cement Slurry Density

Each pozzolanic material has a different specific gravity (SG) that also impacts directly on the density of the cement slurry. The SG of each of the selected pozzolanic materials is lower than the CMCG, as shown Table 1. The experimental results indicated that the density of a cement slurry sample decreased when the amount of the selected pozzolanic material was increased at both room temperature and at 80°C; Figure 5 depicts the relationship of the cement slurry's density and the pozzolanic material's mixing ratio. Moreover, the density of the cement slurry samples measured at 80°C was more than the cement slurry's density at room temperature because of the evaporation of water during testing.

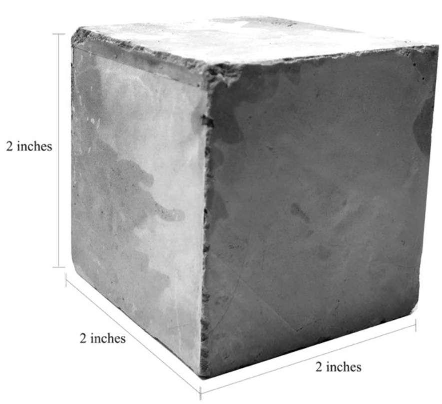


Figure 4. Concrete sample size 2×2×2 inches

Compressive Strength

The results of the compressive strength measurement of the concrete samples showed that the compressive strength of all the selected pozzolanic materials tended to improve when the pozzolanic material to cement mixed ratio was increased at room temperature, as depicted in Figures 6(a), 7(a), and 8(a).

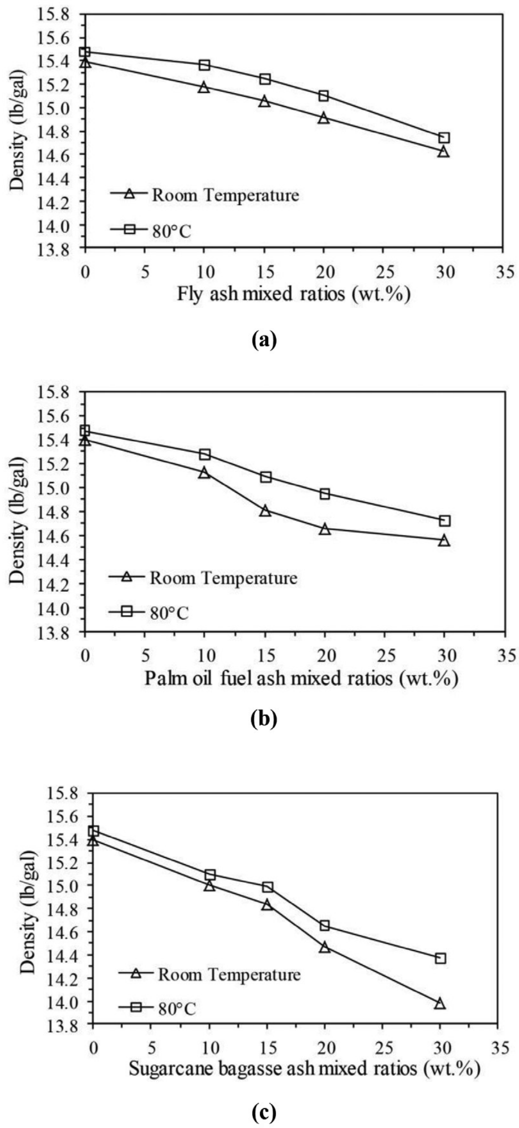


Figure 5. Density of cement slurry versus Pozzolanic material mixed ratios

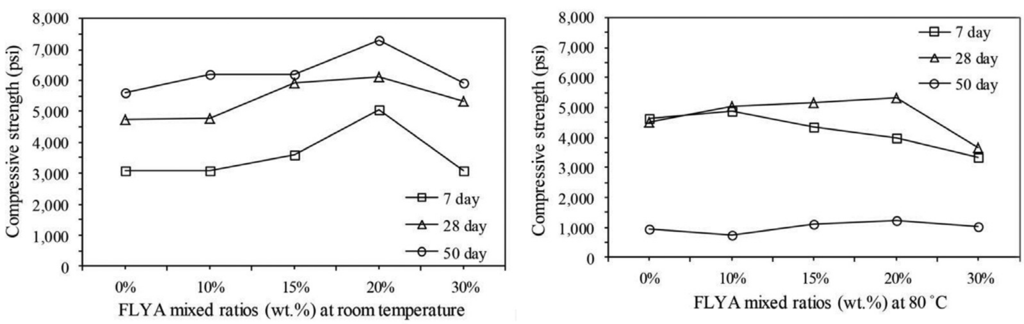
However, it was found that the compressive strength of all the selected pozzolanic materials was reduced when the mixed ratio was higher than 20 wt.%. The main problem of the pozzolanic materials used for the cementitious material mixed into cement is limited to the quantities of $Ca(OH)_2$. An increasing pozzolanic material in the mixed ratio will decrease the amount of cement, and that impacts directly on the quantity of $Ca(OH)_2$ for the pozzolanic reaction. In the addition, the compressive strength of the FLYA was slightly higher than those of the SCBA and POFA concrete for the same mixed ratio, respectively, since the total amount of SiO_2, Al_2O_3, Fe_2O_3, and CaO of each selected pozzolanic material had a direct effect on the strength of the concrete.

Figures 6b, 7b, and 8b depict the experimental results of the concrete samples at a temperature of 80˚C. The results also present the relationship in the same order as the experimental results of the concrete samples at room temperature.

However, the experimental results indicated that the compressive strength of the concrete samples with 50 days concrete curing is much lower than the concrete samples with 7 and 28 days concrete curing at a temperature of 80˚C, respectively. The high temperature can accelerate the hydration reaction (Sukontasukkul, 2006), but the byproducts of the hydration reaction are not well consolidated throughout the entire concrete, which results in decreasing the compressive strength of concrete (Kosmatka *et al*., 2003).

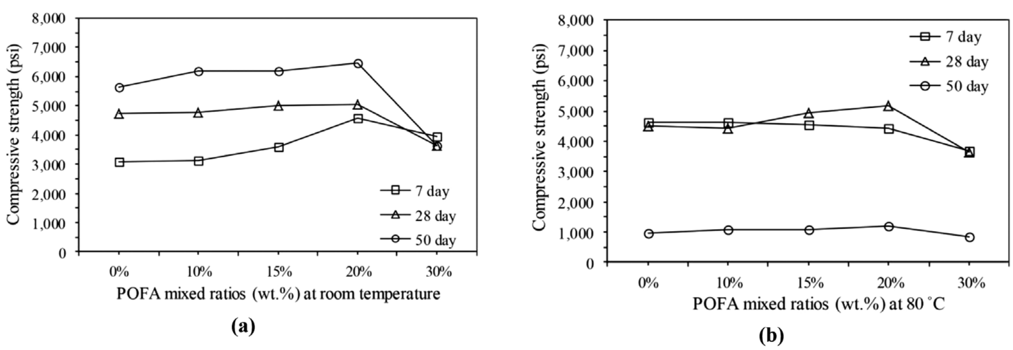
Optimum Mixed Ratios

The density and compressive strength values of the FLYA, POFA, and SCBA cement slurry samples with 28 days of concrete curing at room temperature and at 80°C were plotted to determine the optimum selected pozzolanic



(a) (b)

Figure 6. The compressive strength versus FLYA mixed ratio (wt%)



(a) (b)

Figure 7. The compressive strength versus POFA mixed ratio (wt%)

material to cement mixed ratio, as shown in Figures 9 and 10, respectively.

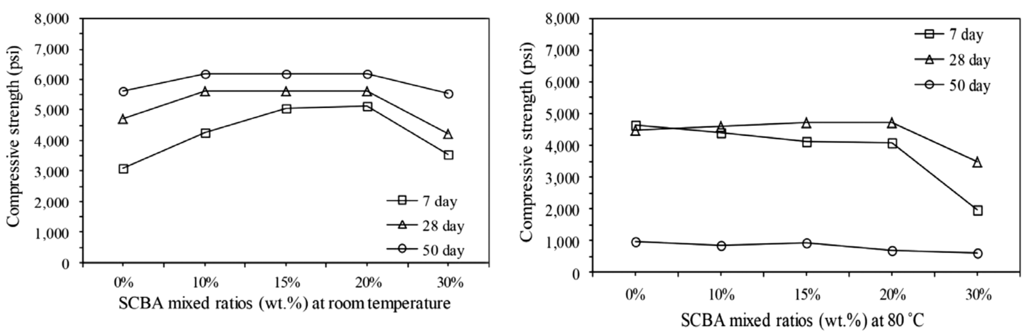
The proper curing time of the cement samples was 28 days based on the compressive strength for both temperatures. The experimental results revealed that the compressive strength of samples with 28 days of concrete curing is higher than samples with 7 days of concrete curing at room temperature and at 80°C. Moreover, the compressive strength of samples with 28 days of curing time is also higher than samples with 50 days of curing time for the temperature at 80°C. In addition, it can be observed that the pozzolanic material to cement mixed ratio at both temperatures at 20 wt.% for all the materials has the highest compressive strength compared to 10, 15, and 30 wt.%. Therefore, the proper FLYA, POFA, and SCBA to cement mixed ratio should be in the range between 15 and 20 wt.% following the experimental results.

Conclusions

Following the study of using fly ash, palm oil fuel ash, and sugarcane bagasse ash as an improvement additive for API class G cement, some conclusions can be drawn as follows:

i) The density of the FLYA, POFA, and SCBA cement slurries depends on the mixed ratio. The amount of the added pozzolanic material can reduce the cement slurry's density. Under the same conditions, the density of the cement slurry with the SCBA was lower than the cement slurries with the POFA and FLYA, respectively.

ii) The compressive strength of the cement



(a) (b)

Figure 8. The compressive strength versus SCBA mixed ratio (wt%)

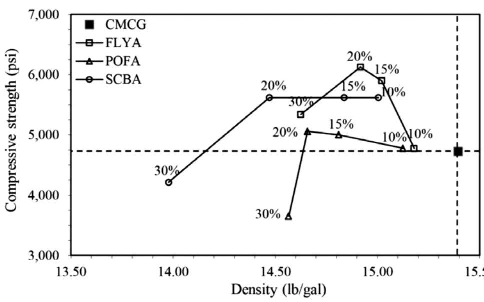


Figure 9. The relationship between compressive strength of 28-day concrete samples and density at room temperature

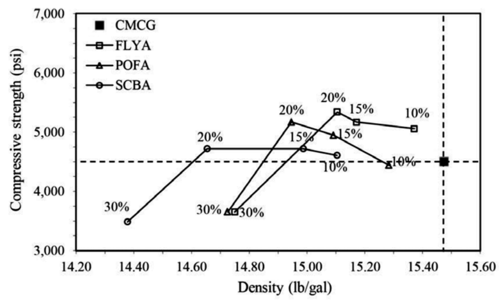


Figure 10. The relationship between compressive strength of 28-day concrete samples and density at 80°C

with the selected pozzolanic materials was increased when the mixed ratio was increased for both temperatures. However, the strength of the concretes was reduced if the selected pozzolanic materials mixed into the cement slurry were more than 20 wt.%, since the $Ca(OH)_2$, an essential component for the pozzolanic reaction, was decreased.

iii) Following the experimental results the optimum range of the weight percent of cement with the FLYA, POFA, and SCBA mixes is between 15% and 20% for the highest compressive strength value. The density of the cement slurry is also appropriate for this optimum range because the cement slurry density is lighter than typical cement. This shows good promise for the use of these waste materials in the petroleum industry.

Acknowledgments

The authors gratefully acknowledge the School of Geotechnology, Institute of Engineering, Suranaree University of Technology for providing financial support and facilities.

References

Berry, E.E. and Malhotra, V.M. (1980). Fly ash for use in concrete. ACI Journal, 77:59-73.

Chindaprasirt, P., Homwuttiwong, S., and Jaturapitakkul, C. (2007). Strength and water permeability of concrete containing palm oil fuel ash and rice husk–bark ash. Constr. Build. Mater., 21(7):1492-1499.

Chindaprasirt, P., Jaturapitakkul, C., and Rattanasak, U. (2009). Influence of fineness of rice husk ash and additives on the properties of lightweight aggregate. Fuel 88(1):158-162.

Halliburton Company. (2003). Micro fly ash cement. Houston, TX, USA: Halliburton Company. Available from: http://www.halliburton.com/en-US/ps/cementing/materials-chemicals-additives/cement-blends/micro-fly-ash-cement.page?node-id=hfqelabn. Accessed date:12 March 2017.

Kosmatka, S.H., Panarese, W.C., and Kerkhoff, B., (2003). Design and Control of Concrete Mixtures. 14^{th} ed. Portland Cement Association, Skokie, IL, USA, 358p.

Mitchell, R.F. (2006). Petroleum Engineering Handbook. Volume II: Drilling Engineering. Society of Petroleum Engineers, Richardson, TX, USA, 763p.

Naik, T.R. and Singh, S.S. (1995). Use of high-calcium fly ash in cement based construction materials. Proceedings of the 5th CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, Supplementary Papers; June 4-9, 1995;Milwaukee, WI, USA, p. 1-44.

Serametjakun, P. (2001). Utilization of limestone powder with pozzolanic material, [MSc. thesis], Thammasat University, Bangkok, Thailand, 146p.

Sukontasukkul, P. (2006). Concrete fundamentals. King Mongkut's University of Technology North Bangkok, Bangkok, Thailand, 179p.