EnvironmentAsia
The international journal published by the Thai Society of Higher Education Institutes on Environment

Available online at www.tshe.org/EA
EnvironmentAsia 8(1) (2015) 75-85

Influences of Fly Ash on Concrete Product's Properties and Environmental Impact Reduction

Thipsuree Kornboonraksa [a] and Thirdpong Srisukphun [b]

[a] *Faculty of Public Health, Thammasat University, Pathumthani 12121, Thailand*
[b] *Faculty of Public and Environmental Health, Huachiew Chalermprakiet University, Samutprakarn 10540, Thailand*

Abstract

This research aimed to study effects of incorporating fly ash into concrete products. Scope of this study were (1) hazard identification of fly ash (2) study on standard testing of various concrete products and (3) study on environmental impact assessment of concrete products mixed with fly ash. Various types of fly ash namely A, B, C and D were sampling from different power plants. Hazard identification of fly ash was analyzed in terms of total threshold limit concentration (TTLC) and soluble threshold limit concentration (STLC). It was found that concentrations of chromium, cadmium, lead, mercury, nickel, zinc, copper and arsenic passed the criteria of notification of the ministry of industry regarding disposal of wastes or unusable materials B.E. 2548 (2005) in appendix-2.Three types of concrete products namely brick road, concrete block and ready mixed concrete were studied. Fly ash was used as cementitious materials to replace Portland cement at 10% and 30%mixture. Concrete products with proportion of fly ash showed lower compressive strengths during 28 days of curing times. However, increase of curing times showed higher compressive strengths for all types of concrete products. ANOVA analysis showed that different fly ash proportion and curing times had a significant effect on compressive strength. The method of CML2 baseline 2000, SimaPro 7.3 was used in environmental impact assessment. The functional unit was set up through working area of 1 m^3. It was found that concrete products mixed with fly ash showed lower environmental impact compared to concrete products without fly ash. Increasing proportion of fly ash showed decreased environmental impact. From ANOVA analysis, there was no significant effect of fly ash types on environmental impact reduction for all types of concrete products. However, % fly ash mixture showed significant effect on environmental impact reduction especially in terms of global warming. Decrease in global warming (GW) potential for block road, concrete block and ready mixed concrete with 10% fly ash mixture were 6.15% - 6.16%, 8.44% - 8.46% and 9.31% - 9.32% whereas the concrete products with 30% fly ash mixture were 18.41% - 18.46%, 25.35% - 25.41% and 25.22% - 25.26% respectively.

Keywords: fly ash; Portland cement; global warming potential; ANOVA analysis

1. Introduction

Portland cement is one of the key ingredients in concrete. However, manufacturing of Portland cement showed negative environmental impact due to CO_2 emissions. Approximately 7% of global CO_2 emissions were caused by cement plants (Ali *et al*., 2011). Previous study found that average CO_2 emissions were 0.9 kg CO_2/kg cement. (Emad *et al*., 2013) CO_2 also emitted from energy usage during the production process (Marcela and Nadezda, 2013). Ang *et al*. (2011) studied on global carbon emissions from electricity with 129 countries. They found that aggregated emission intensity exceeded 1.0 Mt CO_2/TWh in several countries while it was less than 0.1 Mt CO_2/TWh in some countries. To reduce the use of Portland cement, alternative cementitious materials such as fly ash can be adopted. The reactions of fly ash working as a pozzolans were similar to the reactions observed with Portland cement (Celik *et al*., 2014). Therefore, using fly ash instead of Portland cement promoted environmental benefits (Heede and Belie, 2012; Alexandre *et al*., 2013; Khalil *et al*., 2014). Fly ash is the naturally-occurring products from a coal combustion process. It can be collected from the exhaust gases by electrostatic precipitators or bag filters. Particles of fly ash are generally spherical in shape and have a size similar to that of Type I Portland cement. Fly ash particle sizes were reported to be approximately 0.02-90 μm (Katarzyna and Dominik, 2013). Chemical composition of fly ash mostly consists of 40%-60% silicon dioxide (SiO_2), 25%-30% aluminium oxide (Al_2O_3), 6%-15% iron oxide (Fe_2O_3) and small amount of calcium oxide (CaO) (Ahmaruzzaman, 2010; Dale *et al*., 2011) while the composition of a typical Portland cement is about 65% calcium oxide and the rest is generally a mixture of aluminum, iron and silica (Mohammed *et al*., 2012). Previous study showed that concrete containing fly ash pozzolans was denser, stronger and generally more durable in a long term when compared to straight Portland cement concrete mixtures (Mroueh *et al*., 2001; USEPA *et al*., 2005; Eskioglou and Oikonomou, 2008;

Jadambaa *et al*., 2013). However, fly ash also showed the disadvantage in reducing a rate of compressive strength development (Alireza *et al*., 2013). In concrete industry, fly ash was to replace Portland cement at 15%-50% depending on quality of fly ash (Michael, 2014). Many industries in Thailand uses coal as a fuel to produce energy and consequently fly ash emitted as a waste. According to the notification of the ministry of industry on disposal of wastes or unusable materials B.E.2548 (2005) in appendix-2, (Ministry of Industry, Thailand, 2005), fly ash is considered as a waste with possibility to pollute the environment and requires an appropriated disposal. However, fly ash could be considered as a reuse material if chemical properties of fly ash show non-hazardous waste characteristics. Therefore, this research aimed to study the influence of fly ash on concrete products. Four type of fly ash were collected from different sites in order to determine effects of fly ash types on concrete products. Both concrete's properties and environmental impact reduction were investigated. Various concrete products such as block road, concrete block and ready mixed concrete were mixed with different proportions of fly ash. Influence of fly ash on concrete products was study in terms of compressive strength, quality of concrete products based on standard criteria and environmental impact assessment. The method of CML2 baseline 2000, SimaPro 7.3 was used for assessment of environmental impact. ANOVA test with alpha value of 0.05 were performed to evaluate the significance level of all variation factors that affect concrete properties or environmental impact reduction.

2. Materials and Methods

2.1. Properties of fly ash

The quality of fly ash in terms of chemical composition depends on coal types and sources while physical composition depends on power plant processing conditions and collection system (Yang *et al*., 2013). In this study, fly ash namely A, B, C and D were produced from the different sources of coal with different fly ash collecting technologies. The sources and collecting methods are listed in Table 1. Specific density of fly ash was lower than Type I Portland cement typically 3.15 (Michael and John, 2006). This make concrete products mixed with fly ash had a lighter weight than ordinary Portland cement.

2.2. Hazard identification of fly ash

Fly ash was selected as cementitious materials and used instead of Portland cement in the appropriated quantity. However, it must be proved to be non-hazardous waste before apply. The notification of the ministry of industry regarding disposal of wastes or unusable materials B.E. 2548 (2005) in appendix-2 provided the testing methods and maximum value allowable of total threshold limit concentration (TTLC) and soluble threshold limit concentration (STLC). In this study, hazard identification of fly ash was studied in terms of concentration of chromium, cadmium, lead, mercury, nickel, zinc, copper and arsenic.

2.3. Standard testing of various concrete products mixed with fly ash

Three types of concrete products were tested using different standard method. Block road was analyzed in terms of top layer thickness and compressive strength according to TIS.827-2531. Concrete block was analyzed in terms of % water absorption and compressive strength according to TIS.58-2530. Finally, ready mixed concrete was analyzed in terms of slump and compressive strength according to ASTM C143 and ASTM C192. In this study, for all concrete products, Portland cement was replaced by fly ash at proportions of 10% and 30% respectively. The replacement proportion will later be referred to as % fly ash mixture.

2.4. Environmental impact assessment of concrete products

In order to actually take into account of environmental impact, the environmental impact assessment should to conduct. One useful tool to evaluate the environmental impact is Life Cycle Assessment (LCA) (Gjalt and Mary, 2012). The

Table 1. Fly ash characteristics

Sample	Collecting technology	Type of coal	Specific density	%Moisture content
A	Cyclone with bag filter	Bituminous	1.68	5.5
B	Bag filter	Bituminous	2.66	5.5
C	Cyclone with bag filter	Sub-bituminous	1.67	7.0
D	Electrostatic precipitation	Bituminous	2.69	6.3

Table 2. Amounts of materials and energy used in preparing different concrete products

Concrete product	Materials	Quantity	0% Fly Ash	10% Fly Ash	30% Fly Ash
Block road	Portland cement	kg	34.61	31.61	25.68
	Fly ash	kg	0	2.96	8.89
	Coating powder	kg	0.99	0.99	0.99
	Crushed gravel	kg	39.51	39.51	39.51
	Fine sand	kg	69.14	69.14	69.14
	Water	kg	13.43	13.43	13.43
	Electricity	kWh		0.196	
Concrete block	Portland cement	kg	20.24	18.22	14.17
	Fly ash	kg	0	2.02	6.07
	Crushed gravel	kg	50.61	50.61	50.61
	Fine sand	kg	50.61	50.61	50.61
	Water	kg	10.12	10.12	10.12
	Electricity	kWh		0.1678	
Ready mixed concrete	Portland cement	kg	33.5	30.2	23.5
	Fly ash	kg	0	3.4	10.1
	Stone	kg	105.7	105.7	105.7
	Sand	kg	71.1	82.0[A, C], 84.0[B, D]	76.8[A, C], 82.9[B, D]
	Water	kg	21.2	19.0	19.0
	Electricity	kWh		0.1397	

Note: based on working area of 1 m^2

overall framework of LCA consists of four important aspects including (1) goal and scope definition; (2) life cycle inventory (LCI) analysis; (3) life cycle impact assessment (LCIA); and (4) life cycle interpretation. The results of life cycle impact assessment (LCIA) are an evaluation of product life cycle, on a functional unit basis. Several research studied effects of fly ash on environmental impact using LCA (Christopher and Aris, 2009; Ondova and Estokova, 2014; Tom *et al.*, 2014). In this study, method of CML2 baseline 2000, SimaPro 7.3 was selected to evaluate the environmental impact. Six environmental impact categories were studied in terms of abiotic depletion (AD), acidification (AC), euthrophication (EU), global warming (GW), human toxicity (HT) and photochemical oxidation (PO). Functional unit of this study based on working area of 1 m^2. Scope of environmental impact assessment is depicted by Fig. 1.

2.5. ANOVA tests

Analysis of variance (ANOVA) is the statistic method that used to compare the different distributions of samples by looking at the relationship between a quantitative response variable and source of variation, typically using the F-statistic test (Alexander *et al.*, 2007).The larger F-statistic value show more difference between the samples. In this study, ANOVA tests with

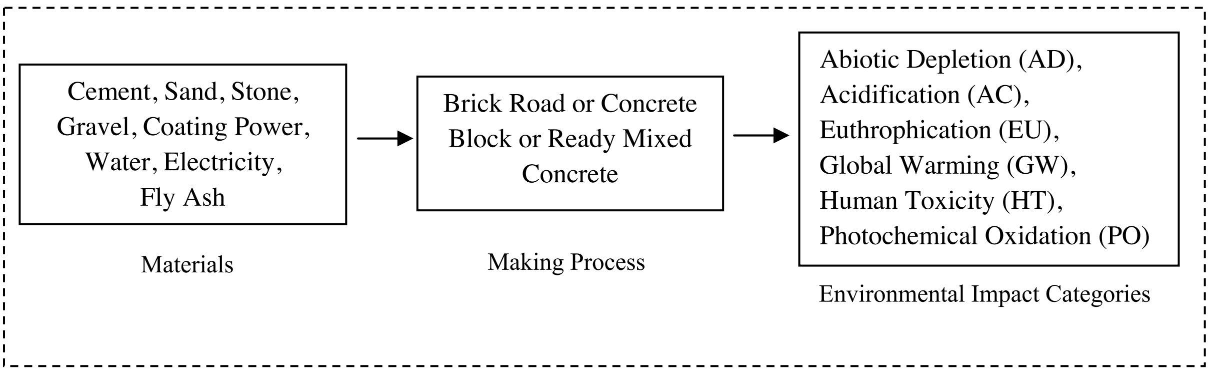

Figure 1. Scope of environmental impact assessment

alpha value of 0.05 were performed to evaluate the significance level of all variations that effect on concrete properties or environmental impact reduction. The variation considered were % fly ash mixture, different types of fly ash and curing times.

3. Results and Discussion

3.1. Hazard identification of fly ash

The results of hazard identification of fly ash in terms of TTLC value and STLC value were shown in Table 3 and Table 4, respectively. The results found that fly ash A, B, C and D had TTLC values lower than TTLC regulatory limit for all parameters. Because their TTLC values of mercury and arsenic were lower than STLC regulatory limit, therefore, mercury and arsenic were excluded from the STLC measurements. The results showed that all fly ash samples had STLC values less than STLC regulatory limits for all parameters. Hence, it could be concluded that all fly ash types (A, B, C and D) were acceptable as non-hazardous waste and can be used as a cementitious materials. Based on ANOVA analysis, all fly ash samples had $F_{statistic}$ value of 2.23 lower than $F_{critical}$ value of 3.27 for TTLC while $F_{statistic}$ value of 0.55 lower than $F_{critical}$ value of 3.29 for STLC. This means that there was no significant difference in terms of TTLC value and STLC value for different types and sources of fly ash. The results of heavy metal leaching from concrete product mixed with bituminous fly ash were studied by Nipapun and Naradol (2011). Results showed that leaching of heavy metals in terms of arsenic, chromium, nickel and zinc ions both TTLC value and STLC value were less than the standard criteria.

3.2. Results of standard testing of concrete products

3.2.1. Effect of %fly ash mixture and curing times on compressive strength

To determine the effect of % fly ash mixture and curing times on compressive strength, different % fly ash mixture varying from 10% to 50% and curing times varying from 14, 28 and 56 days were investigated. The standard criteria were based on the compressive strength of 300 kg/cm^2 at 28 days of curing times. The results of compressive strength with and without fly ash at curing times of 14, 28 and 56 days were shown in Fig. 2. At 14 days of curing times, the compressive strength of concrete without fly ash was 460.9 kg/cm^2.

Table 3. Hazard identification in terms of TTLC

Parameter	TTLC (mg/kg)				TTLC regulatory limit (mg/kg)
	Fly ash A	Fly ash B	Fly ash C	Fly ash D	
Chromium	38.38	19.00	29.76	33.22	500
Cadmium	1.37	17.72	7.23	11.04	100
Lead	10.18	3.25	5.28	17.31	1,000
Mercury	0.041	0.004	0.001	0.004	20
Nickel	84.60	24.03	111.53	49.13	2,000
Zinc	540.17	342.57	485.08	402.39	5,000
Copper	221.10	111.83	196.09	287.59	2,500
Arsenic	3.31	2.16	2.00	3.06	500

Table 4. Hazard identification in terms of STLC

Parameter	STLC (mg/L)				STLC regulatory limit (mg/L)
	Fly ash A	Fly ash B	Fly ash C	Fly ash D	
Chromium	0.22	0.23	0.23	0.19	5
Cadmium	0.03	0.03	0.03	0.03	1
Lead	0.25	0.22	0.22	0.25	5
Mercury	N/A	N/A	N/A	N/A	0.2
Nickel	0.33	0.35	0.30	0.38	20
Zinc	0.05	0.12	0.11	0.09	250
Copper	0.06	0.07	0.06	0.07	25
Arsenic	N/A	N/A	N/A	N/A	5

Note: N/A–did not analyze because TTLC values were less than STLC regulatory limits

Adding more % fly ash mixture from 10%, 20%, 30%, 40% to 50%, the compressive strengths of concrete decreased to 386.1 kg/cm^2, 257.8 kg/cm^2, 246.4 kg/cm^2, 236.7 kg/cm^2 and 179.7 kg/cm^2 respectively. The results indicated that the compressive strength decreased with an increase in % fly ash mixture. This is in accord with previous studies. It was found that pozzolanic reaction of fly ash was a slow process as fly ash particles did not act as binders during the early hydration period (Alireza *et al*., 2013; Seyoon *et al*., 2014).

At 28 days of curing times, the compressive strength of concrete without fly ash was higher than the compressive strength at 14 days curing time, 527.5kg/cm^2 compared with 460.9 kg/cm^2. Addition of fly ash reduced compressive strength: % fly ash mixture from 10% to 50% yielded compressive strengths 469.7 kg/cm^2, 369.5 kg/cm^2, 323.4 kg/cm^2, 299.9 kg/cm^2 and 267.7 kg/cm^2 respectively. Only concretes containing % fly ash mixture of 10%, 20% and 30% could pass the standard criteria of compressive concrete at 300 kg/cm^2 with curing times of 28 days.

However, at 56 days of curing times, all the concretes with or without fly ash could pass the standard criteria. It was observed that compressive strength of concrete slightly increased with time. Compressive strengths of % fly ash mixture from 0% to 50% were 559.1 kg/cm^2, 553.2 kg/cm^2, 492.5 kg/cm^2, 451.1 kg/cm^2, 400.8 kg/cm^2 and 365.7 kg/cm^2 respectively. This is because of hydration and pozzolanic reaction occurred (Soroka, 1993). SiO_2 reacted with calcium oxide and was converted to calcium silicate. The combination of calcium silicate and water turned to calcium silicate hydrate, which improved cementitious function between molecular structures and age hardening of concrete, rendering the increase of compressive strength of concrete (Nipapun and Naradol, 2011). Naik *et al*. (1995) also reported that the longer curing time of concrete mixed with fly ash yielded the better compressive strength of concrete.

The exponential regression of compressive strength with % fly ash mixture at different curing times can be summarized as shown in equation (1) to (3)

Compressive strength at 14 days:

$$y = 436.50e^{-0.018x} \quad ; R^2 = 0.9223 \qquad (1)$$

Compressive strength at 28 days:

$$y = 517.34e^{-0.014x} \quad ; R^2 = 0.9719 \qquad (2)$$

Compressive strength at 56 days:

$$y = 583.10e^{-0.009x} \quad ; R^2 = 0.9735 \qquad (3)$$

When y = compressive strength (kg/cm^2)
x = % fly ash mixture

To find the significance levels of design factor, which indicated how significantly % fly ash mixture and curing times affect compressive strength. Analysis of variance (ANOVA) at a significance level alpha of 0.05 was used in this study. The application of % fly ash mixture from 0% to 50% showed $F_{statistic}$ value of 76.46 which was higher than the corresponding $F_{critical}$ value of 4.10. While the variation of curing times at 14, 28 and 56 days showed $F_{statistic}$ value of 44.00 which was higher than corresponding $F_{critical}$ value of 3.33 $F_{statistic}$ value greater than the $F_{critical}$ value means both variation of % fly ash mixture and curing times significantly affect on compressive strength. Results of ANOVA analysis for this study were summarized in Table 5. Study on effects of variation of % fly ash mixture and curing times on compressive strength by ANOVA tests was also done by Kolapo and Akaninyene (2012). They found that the independent factor such as periwinkle shell ash (PSA) and curing times had a significant effect on compressive strength.

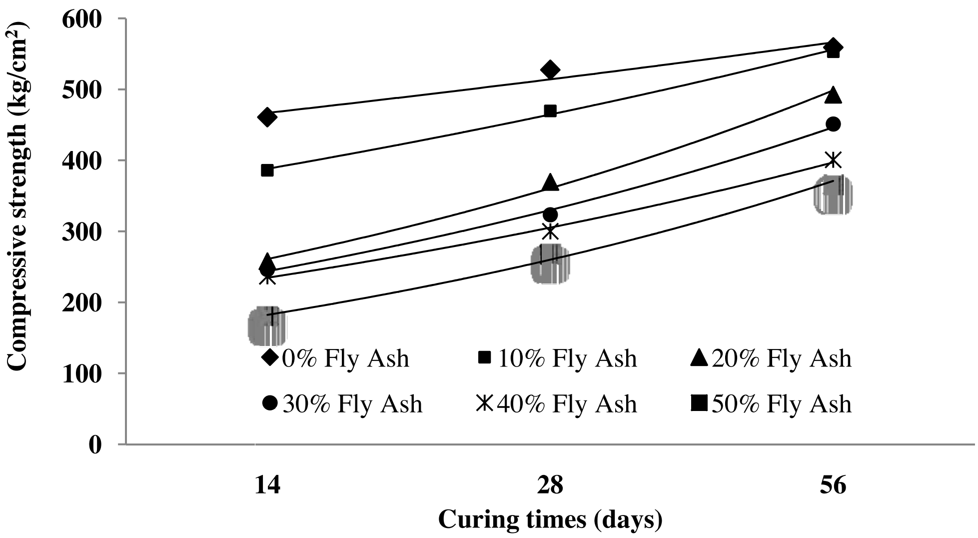

Figure 2. Variation of % fly ash mixture and curing times on compressive strength

Table 5. ANOVA analysis for study the variation of % fly ash mixture and curing times on compressive strength

Source of Variation	$F_{statistic}$ value	$F_{critical}$ value
% Fly ash mixture	76.46	4.10
Curing Times	44.00	3.33

3.2.2. Study on block road

The standard testing of block road was studied based on two parameters. The first parameter was top layer thickness must be higher than 5 mm. The second parameter was strength of concrete must be higher than 350kg/cm^2 after 28 days of curing times. The results showed that top layer thickness of block road containing fly ash A, B, C and D passed the standard criteria at 0% and 10% fly ash mixture as shown in Table 6. Moreover, at this % fly ash mixtures the block roads passed the standard criteria for compressive strength. More proportion of fly ash gave lower compressive strength. ANOVA analysis showed that no significant effect of fly ash types (A, B, C and D) on compressive strength of block road. $F_{statistic}$ value was 0.44 while $F_{critical}$ value 4.76. However, % fly ash mixture showed significant effect on compressive strength as $F_{statistic}$ value of 94.61 was higher than $F_{critical}$ value of 5.14. Costs of raw materials for block road at0%, 10% and 30% fly ash mixture were 4.64 baht/piece, 4.45 baht/piece and 4.06 baht/piece respectively.

3.2.3. Study on concrete block

The standard testing of concrete block was studied based on two parameters, water absorption and compressive strength. The water absorption must be less than 25% whereas compressive strength must be higher than 20 kg/cm^2 after 28 days of curing times. The results found that water absorptions of concrete blocks containing fly ash A, B, C and D were lower than 25% at all % fly ash mixture as shown in Table 6. However, only the concrete blocks containing 0% and 10% fly ash mixture passed the standard criteria for compressive strength. It should be noted that for both block road and concrete block, only the products of 0% and 10% of fly ash mixture passed the standard criteria. ANOVA analysis showed that no significant effect of fly ash types on compressive strength of concrete block. $F_{statistic}$ value was 0.41 whereas $F_{critical}$ value was 4.76. However, % fly ash mixture showed significant effect on compressive strength. $F_{statistic}$ value of 93.69 was higher than $F_{critical}$ value of 5.14. Costs of raw materials

Table 6. Testing of physical parameter for various types of concrete products

Product	Standard value of concrete products	Fly ash	%Fly ash mixture		
			0%	10%	30%
Block road (22.5x11.25x6.0 cm^3)	Top layer thickness not less than 5 mm.	A	5-6	5-6	5-6
		B	5-6	5-6	5-6
		C	5-6	5-6	5-6
		D	5-6	5-6	5-6
	Strength of concrete not less than 350 kg/cm^2 after 28 days incubation	A	528.1	480.3	322.1
		B	528.1	477.7	308.4
		C	528.1	461.2	318.8
		D	528.1	410.5	332.7
Concrete block (19.0x39.0x7.0 cm^3)	Water absorption not higher than 25%	A	16.32	20.31	24.23
		B	16.32	19.78	27.17
		C	16.32	21.11	25.02
		D	16.32	18.33	21.24
	Strength of concrete not less than 20 kg/cm^2 after 28 days incubation	A	30.01	27.29	18.30
		B	30.01	27.14	17.52
		C	30.01	26.20	18.11
		D	30.10	23.32	18.90
Ready mixed concrete (Volume of 1 m^3)	Slump is between 5 and 10 cm	A	8.75	6.92	4.32
		B	8.75	7.52	5.56
		C	8.75	6.32	4.08
		D	8.75	7.39	5.35
	Strength of concrete not less than 300 kg/cm^2 after 28 days incubation	A	527.51	490.11	302.12
		B	527.51	472.90	321.43
		C	527.51	455.30	302.70
		D	527.51	460.47	367.37

Table 7. Comparisons of environmental impact for concrete products without fly ash mixing

Environmental impact	Unit	Block road	Concrete block	Ready mixed concrete
Abiotic depletion (AD)	kg Sb eq	0.1390	0.0521	0.0987
Acidification (AC)	kg SO_2 eq	0.0839	0.0289	0.0569
Eutrophication (EU)	kg PO_4^{3-} eq	0.0224	0.0067	0.0110
Global warming (GW)	kg CO_2 eq	39.4177	19.5509	34.4177
Human toxicity (HT)	kg 1,4-DB eq	7.5548	2.2513	3.5610
Photochemical oxidation (PO)	kg C_2H_4 eq	0.0035	0.0011	0.0022

for concrete block at 0%, 10% and 30% fly ash mixture were 4.81 baht/piece, 4.42 baht/piece and 3.64 baht/piece respectively.

3.2.4. Study on ready mixed concrete

The standard testing of ready mixed concrete was studied using two parameters. The first parameter was slump value should be between 5 and 10 cm. The second parameter was compressive strength must higher than 300 kg/cm^2 after 28 days of curing times. The results found that slump of ready mixed concrete in all samples were in the range of 5-10 mm. Excluding 30% fly ash mixture of sample A and C (Table 6). However, compressive strengths of all samples passed the standard criteria. Compressive strengths of fly ash A, B, C and D were 302.12 km/cm^2, 321.43 km/cm^2, 302.70 km/cm^2 and 367.37 km/cm^2, respectively. ANOVA analysis showed that no significant effect of fly ash types on compressive strength of ready mixed concrete. $F_{statistic}$ value was 0.60 while $F_{critical}$ value was 4.76. Nevertheless, % fly ash mixture showed significant effect on compressive strength. $F_{statistic}$ value of 97.50 was higher than $F_{critical}$ value of 5.14. Costs of raw materials for ready mixed concrete at 0%, 10% and 30% fly ash mixture were 1,099.12 baht/m^2, 1,021.82 bath/m^2 and 843.46 baht/m^2 respectively.

3.3. Results of environmental impact assessment

3.3.1. Concrete products without fly ash

Environmental impact assessment was done by CML2 baseline 2000 method, SimaPro 7.3 Software. It was found that block road showed the highest environmental impact in all categories followed by ready mixed concrete and concrete block as shown in Table 7. Approximately, concrete block showed lower environmental impact than block road ranging from 29.8% to 37.5% for all categories except global warming impact. Ready mixed concrete showed lower environmental impact than block road ranging from

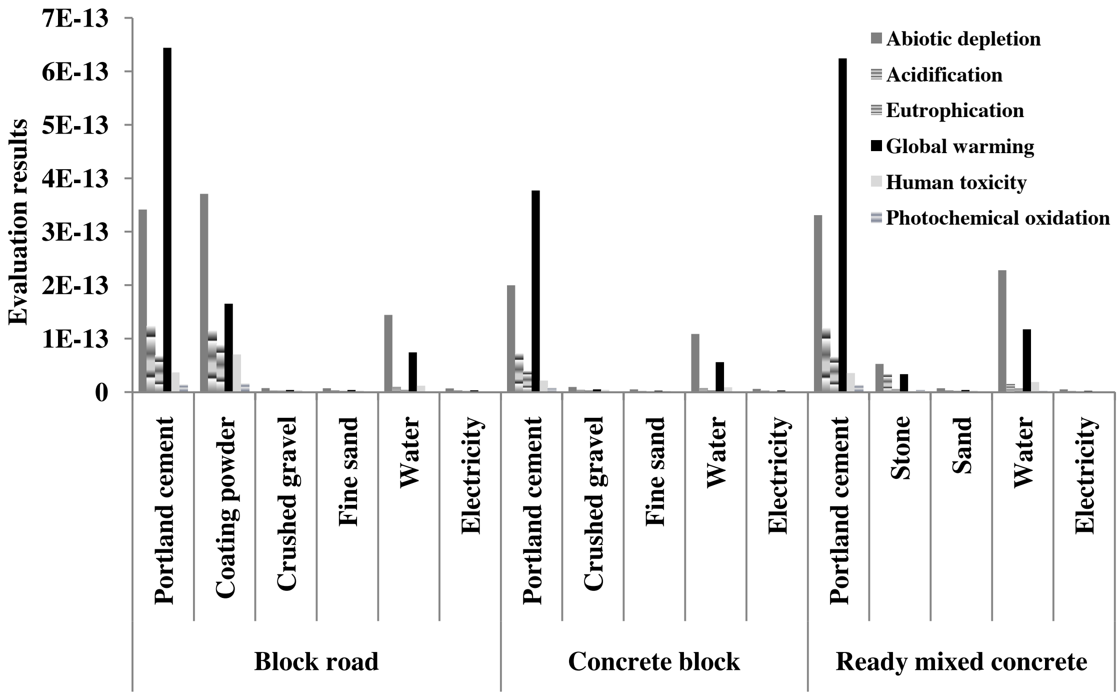

Figure 3. Normalized LCA impact categories with CML 2 baseline 2000/ World, 1990

Table 8. Reduction of CO_2 emission due to reduction of Portland cement usage

Reduction of CO_2 emission	Unit	10% Fly ash mixture	30% Fly ash mixture
Block road	kg CO_2 eq	2.46	7.33
Concrete block	kg CO_2 eq	1.66	4.98
Ready mixed concrete	kg CO_2 eq	2.71	8.21

47.1% to 71.0% for all categories also except global warming impact. In terms of global warming impact, block road showed 39.4177 kg CO_2 eq and ready mixed concrete showed 34.4177 kg CO_2 eq (or 87.3% of global warming impact compared to block road) whereas concrete block showed 19.5509 kg CO_2 eq. (or 49.6% of global warming impact compared to block road).

To find the key factor that causes global warming potential, a normalization step is required. A normalization step is widely exercised in LCA studies in order to better understand the relative significance of impact category results (Junbeum *et al*., 2013). The normalization results are expressed in the same unit for each impact score makes it easier to make comparisons between impact scores of different impact categories (Anneke *et al*., 2008). According to normalized LCA impact categories (Fig. 3), the results showed that Portland cement produced highest global warming potential compared to other materials or energy usage. The more Portland cement used leads to more global warming impact. Therefore, based on the results in this study, Portland cement was a key factor that influenced on global warming potential.

To calculate the effect of fly ash replacement Portland cement on reduction of CO_2 emissions, average CO_2 emissions per kg cement was required. The result from SimaPro 7.3 analysis showed that average CO_2 emissions were 0.8207 kg CO_2/kg cement which was similar to previous study (Emad *et al*., 2013). According to Table 2, decrease of Portland cement by replacement of 10% and 30% fly ash mixture showed the reduction of CO_2 emissions as shown in Table 8.

3.3.2. Concrete products with fly ash

The results demonstrated that using more % fly ash mixture showed lower environmental impact for

Table 9. Percent environmental impact reduction for block road

Environmental impact reduction		AD (kg Sb eq)	AC (kg SO_2 eq)	EU (kg PO_4^{3-} eq)	GW (kg CO_2 eq)	HT (kg 1,4-DB eq)	PO (kg C_2H_4 eq)
10% Fly Ash	A	0.1345	0.0810	0.0218	36.9927	7.5139	0.0034
	B	0.1349	0.0806	0.0217	36.9948	7.4242	0.0034
	C	0.1346	0.0811	0.0218	36.9922	7.5051	0.0034
	D	0.1347	0.0808	0.0218	36.9903	7.5273	0.0034
30% Fly Ash	A	0.1254	0.0753	0.0207	32.1592	7.4334	0.0032
	B	0.1266	0.0742	0.0204	32.1410	7.2057	0.0032
	C	0.1259	0.0757	0.0206	32.1576	7.4069	0.0032
	D	0.1261	0.0748	0.0207	32.1517	7.4735	0.0032

Table 10. Percent environmental impact reduction for concrete block

Environmental impact reduction		AD (kg Sb eq)	AC (kg SO_2 eq)	EU (kg PO_4^{3-} eq)	GW (kg CO_2 eq)	HT (kg 1,4-DB eq)	PO (kg C_2H_4 eq)
10% Fly Ash	A	0.0491	0.0270	0.0063	17.9017	2.2240	0.0010
	B	0.0493	0.0267	0.0062	17.8975	2.1721	0.0010
	C	0.0492	0.0271	0.0063	17.9013	2.2179	0.0011
	D	0.0492	0.0269	0.0063	17.9000	2.2331	0.0010
30% Fly Ash	A	0.0429	0.0231	0.0055	14.5949	2.1686	0.0009
	B	0.0437	0.0223	0.0053	14.5825	2.0130	0.0009
	C	0.0432	0.0233	0.0055	14.5939	2.1505	0.0009
	D	0.0434	0.0228	0.0055	14.5898	2.1961	0.0009

Table 11. Percent environmental impact reduction for ready mixed concrete

Environmental impact reduction		AD (kg Sb eq)	AC (kg SO_2 eq)	EU (kg PO_4^{3-} eq)	GW (kg CO_2 eq)	HT (kg 1,4-DB eq)	PO (kg C_2H_4 eq)
10% Fly Ash	A	0.0901	0.0534	0.0103	31.2128	3.4304	0.0021
	B	0.0906	0.0530	0.0102	31.2106	3.3481	0.0020
	C	0.0903	0.0535	0.0103	31.2122	3.4203	0.0021
	D	0.0904	0.0532	0.0103	31.2147	3.4506	0.0021
30% Fly Ash	A	0.0799	0.0469	0.0089	25.7298	3.3265	0.0018
	B	0.0812	0.0457	0.0086	25.7239	3.0824	0.0018
	C	0.0804	0.0473	0.0089	25.7281	3.2964	0.0018
	D	0.0807	0.0464	0.0090	25.7360	3.3868	0.0018

Table 12. ANOVA analysis for study the variation of fly ash types on environmental impact reduction

Effect of fly ash type on environmental impact reduction	Block road		Concrete block		Ready mixed concrete	
	$F_{statistic}$ value	$F_{critical}$ value	$F_{statistic}$ value	$F_{critical}$ value	$F_{statistic}$ value	$F_{critical}$ value
Abiotic depletion	5.00	9.28	4.00	9.28	4.05	9.28
Acidification	4.15		4.00		4.07	
Eutrophication	7.45		4.00		4.07	
Global warming	0.62		4.00		4.03	
Human toxicity	5.18		4.00		4.06	
Photochemical oxidation	3.97		4.00		4.07	

Table 13. ANOVA analysis for study the variation of % fly ash mixture on environmental impact reduction

Effect of fly ash type on environmental impact reduction	Block road		Concrete block		Ready mixed concrete	
	$F_{statistic}$ value	$F_{critical}$ value	$F_{statistic}$ value	$F_{critical}$ value	$F_{statistic}$ value	$F_{critical}$ value
Abiotic depletion	3443.32	10.13	2963.70	10.13	2508.43	10.13
Acidification	750.39		735.63		851.32	
Eutrophication	1030.38		678.97		759.32	
Global warming	1.07E+06		3.12E+06		1.06E+07	
Human toxicity	9.58		8.60		10.05	
Photochemical oxidation	637.19		642.30		735.53	

all categories. The reduction of environmental impact was highest in global warming potential (GW) due to fly ash was used instead of Portland cement. Decrease in global warming (GW) for block road, concrete block and ready mixed concrete at 10% fly ash mixture were 6.15% - 6.16%, 8.44% - 8.46% and 9.31% - 9.32% whereas at 30% fly ash mixture were 18.41% - 18.46%, 25.35% - 25.41% and 25.22% - 25.26% respectively. Reductions of other environmental impact categories are shown in Table 9-11.The effect of fly ash types on environmental impact reduction was analyzed by ANOVA. It was found that, $F_{statistic}$ values were lower than $F_{critical}$ value as shown in Table 12. Therefore, there was no significant effect of fly ash type on environmental impact reduction for any concrete products. The effect of % fly ash mixture on environmental impact reduction was also investigated by ANOVA. However, it showed the different results. $F_{statistic}$ values were higher than $F_{critical}$ value as shown in Table 13. From this result, it could be concluded that there was significant effect of % fly ash mixture on environmental impact reduction.

4. Conclusions

The conclusions of this study were summarized here.

(1) Hazard identification of fly ash A, B, C and D was analyzed in terms of TTLC values and STLC values. It was found that all of fly ash sample showed lower TTLC values and STLC values than regulatory limits. ANOVA analysis showed that there was no

significant difference in terms of TTLC values and STLC values for different types and sources of fly ash.

(2) ANOVA analysis showed that compressive strength of concrete decreased with the increase in % fly ash mixture and curing times. The exponential regression of compressive strength with % fly ash mixture at different curing times of 14 days, 28 days and 56 days were $y = 436.50e^{-0.018x}$, $R^2 = 0.9223$; $y = 517.34e^{-0.014x}$, $R^2 = 0.9719$ and $y = 583.10e^{-0.009x}$, $R^2 = 0.9735$ respectively.

(3) Portland cement was found to be the key factor that influenced global warming potential. Hence, using coal fly ash as a cementitious material instead of Portland cement reduced the global warming potential significantly. However the main disadvantage of fly ash was the reduced rate of compressive strength development.

(4) Application of fly ash to replace Portland cement showed the benefit in reducing the environmental impact. Higher % fly ash mixture yielded lower environmental impact categories especially in terms of global warming. ANOVA analysis showed that there was no significant effect of fly ash types on environmental impact reduction. However, ANOVA analysis confirmed significant effect of % fly ash mixture on environmental impact reduction.

References

Ahmaruzzaman M. A review on the utilization of fly ash. Progress in Energy and Combustion Science 2010; 36(3): 327-63.

Alexander V, Andrew W, Rohan P, Ibrahim O. Factor analysis and ANOVA. Process Dynamics and Controls Open Textbook, University of Michigan Chemical Engineering, USA. 2007.

Alexandre SDV, Angela BM, Denise DM, Antônio CFV. The use of alkali-activated fly ash in the production of cement with reduced environmental impact. *In*: Fly ash: sources, applications and potential environmental impacts (*Ed*: Prabir KS). Nova Science Publishers, Inc., USA. 2013; 245-70.

Ali MB, Saidur R, Hossain MS. A review on emission analysis in cement industries. Renewable and Sustainable Energy Reviews 2011; 15(5): 2252-61.

Alireza B, Hamed Z, Hadi A, Mohammad S, Mohammad ASM. Comparing the performance of fine fly ash and silica fume in enhancing the properties of concretes containing fly ash. Construction and Building Materials 2013; 47: 1402-08.

Ang BW, Zhou P, Tay LP. Potential for reducing global carbon emissions from electricity production-a benchmarking analysis. Energy Policy 2011; 39(5): 2482-89.

Anneke WS, Lauran FCMO, Jeroen BG, Jaap S, Mark AJH. Normalisation in product life cycle assessment: an LCA of the global and European economic systems in the year 2000. Science of The Total Environment 2008; 390(1): 227-40.

Celik K, Meral C, Mancio M, Mehta PK, Monteiro PJM. A comparative study of self-consolidating concretes incorporating high-volume naturalpozzolan or high-volume fly ash. Construction and Building Materials 2014; 67(part A): 14-19.

Christopher JK, Aris TD. Environmental assessment of the cement and concrete life cycle in Greece. International Journal of Environmental Technology and Management 2009; 10(1): 71-88.

Dale PB, Andrew SH, John MG. Optimization of cement and fly ash particle sizes to produce sustainable concretes. Cement and Concrete Composites 2011; 33(8): 824-31.

Emad B, Gholamreza Z, Ezzatollah S, Alireza B. Global strategies and potentials to curb CO2 emissions in cement industry. Journal of Cleaner Production 2013; 51: 142-61.

Eskioglou P, Oikonomou N. Protection of environment by the use of fly ash in road construction. Global NEST Journal 2008; 10(1): 108-13.

Gjalt H, Mary AC. Environmental life cycle assessment: background and perspective. *In*: Life cycle assessment handbook: a guide for environmentally sustainable products (*Ed*: Mary AC). Scrivener Publishing LLC., Canada. 2012; 1-14.

Heede PVD, Belie ND. Environmental impact and life cycle assessment (LCA) of traditional and 'green' concretes: literature review and theoretical calculations. Cement and Concrete Composites 2012; 34(4): 431-42.

Jadambaa T, William R, Arie VE. Characterization of various fly ashes for preparation of geopolymers with advanced applications. Advanced Powder Technology 2013; 24(2): 495-98.

Junbeum K, Yi Y, Junghan B, Sangwon S. The importance of normalization references in interpreting life cycle assessment results. Journal of Industrial Ecology 2013; 17(3) 385-95.

Katarzyna JR, Dominik K. Size distribution and trace elements contents of coal fly ash from pulverized boilers. Polish Journal of Environmental Studies 2013; 22(1): 25-40.

Khalil NM, Hassan EM, Shakdofa MME, Farahat M. Beneficiation of the huge waste quantities of barley and rice husks as well as coal fly ashes as additives for Portland cement. Journal of Industrial and Engineering Chemistry 2014; 20(5): 2998-3008.

Kolapo OO, Akaninyene AU. Strength characteristics of periwinkle shell ash blended cement concrete. International Journal of Architecture, Engineering and Construction 2012; 1(4): 213-20.

Marcela O, Nadezda S. Environmental assessment of fly ash concrete. Chemical Engineering Transactions 2013; 35: 841-46.

Michael SM, John PZ. Materials for civil and construction engineers. 2nd ed. Pearson Education, Inc., New Jersey, USA. 2006; 201-04.
Michael T. Optimizing the use of fly ash in concrete. Portland Cement Association 2014; 1-24.
Ministry of Industry. Appendix-2 in Notification of the ministry of industry on disposal of wastes or unusable materials B.E. 2548 (2005). Thailand: Ministry of Industry; 2005: 44-54.
Mohammed SI, Collette C, Sean M. Trends and developments in green cement and concrete technology. International Journal of Sustainable Built Environment 2012; 1(2): 194-216.
Mroueh UM, Eskola P, Laine-Ylijoki J. Life-cycle impacts of the use of industrial by-products in road and earth construction. Waste Management 2001; 21(3): 271-77.
Naik TR, Ramme BW, Tews JH. Pavement construction with high-volume class C and class F fly ash concrete. ACI (American Concrete Institute) Materials Journal 1995; 92: 200-10.
Nipapun K, Naradol T. Application of bituminous fly ash for partial replacement of cement in producing hollow concrete blocks. Asia Journal of Public Health 2011; 2(3): 15-21.
Ondova M, Estokova A. LCA and multi-criteria analysis of fly ash concrete pavements. International Journal of Environmental, Ecological, Geological and Mining Engineering 2014; 8(5): 308-13.
Seyoon Y, Paulo JMM, Donald EM, Fredrik PG, Mohammed SI. Statistical evaluation of the mechanical properties of high-volume class F fly ash concretes. Construction and Building Materials 2014; 54: 432-42.
Soroka I. Concrete in hot environments. 1st ed. E.&F.N. SponPublisher, London, UK. 1993; 51-53.
Tom B, Peter S, Hans V. Reducing the environmental impact of concrete and asphalt: a scenario approach. Journal of Cleaner Production 2014; 66: 27-36.
United States Environmental Protection Agency, Department of Energy, The American Coal Ash Association and The Utility Solid Waste Activities Group. Using coal ash in highway construction: a guide to benefits and impacts. National Service Center for Environmental Publications, USA. 2005; 1-2.
Yang D, Jinder J, Jianhui S, Shih-Yaw L. Fly ash separation technology and its applications. Center for Applied Energy Research, University of Kentucky. 2013; 1-11.

Received 4 April 2014
Accepted 30 September 2014

Correspondence to
Dr.Thipsuree Kornboonraksa
Faculty of Public Health,
Thammasat University,
Pathumthani 12121,
Thailand
Tel: +66-94-536-5545
Email: thipsuree@gmail.com