Fifth International Conference on Construction in the 21st Century (CITC-V)
"Collaboration and Integration in Engineering, Management and Technology"
May 20-22, 2009, Istanbul, Turkey

The Effects of Limestone Powder and Pulverized Fuel Ash on Compressive Strength of Casting Concrete in Hollow Core Slab Manufacturing Process

Patcharaporn Yanpirat, Sansanee Supapa
Department of Industrial Engineering, Faculty of Engineering, Kasetsart University (Main Campus), Bangkok, Thailand
fengppy@ku.ac.th, fengsas@ku.ac.th

Chaiyarun Wuttivoradit
Engineering Management Program, Faculty of Engineering, Kasetsart University (Main Campus), Bangkok, Thailand
chaiyarun@hotmail.com

Abstract
The proportions of substitute substances in concrete mixture depend upon the required properties of product produced and anticipated acquisition costs. Limestone powder and pulverized fuel ash are the potential substances widely used in manufacture of concrete products. The objective of this paper was to analyze the effects of limestone powder and pulverized fuel ash treated as substitute substances of Portland cement in terms of compressive strength of concrete casting in hollow core slab manufacturing process of the selected case study. Design of experiment with single and two factors analysis was employed to analyze the main effect as well as interaction effect of co-substance. The relationship between compressive strength and the proportion of substance substitution was also analyzed by the regression analysis. The findings revealed limestone powder and pulverized fuel ash could vary individually with 0-15% and 0-20% by volume, respectively, without any effects to the quality of the final product. And no interaction effect between them in enhancing the compressive strength of the concrete products was significant revealed. Based on the economic point of view limestone powder was the challenge alternative filler to the manufacturer with attractive cost savings.

Keywords
Concrete technology, Hollow core slab, Compressive strength, Limestone powder, Pulverized fuel ash

1. Introduction

The use of limestone or pulverized fuel ash filler is a common practice in manufacturing cement products. Not only does the economic benefits in reducing production and investment costs but also the technical benefits on increasing of early strength, the control of bleeding in concrete, and the low sensibility of the lack of curing are expected. The optimum replacement level of cement with filler such as limestone powder or pulverized fuel ash depended on the concrete mixture proportions in other words the percentage of filler added had to increase when the water/cement ratio used in the mixing process was decreased (Bonavetti *et al.*, 2003). Partial replacement of cement with such filler lowered the material cost and the early-age strength but increased the long-term strength of concrete. Tsivilis *et al.* (2000) suggested the range of limestone for replacement could be used up to 20% which resulted in satisfactory concrete strength, workability, and optimum protection against rebar corrosion. In addition, it demanded less water than the relative pure cement because the fineness of clinker and limestone is strongly connected with the limestone content resulted in the improvement in the clinker reactivity and the exploitation of its hydraulic potential (Tsivilis *et al.*, 2002). Besides the w/c ratio, the compressive strength of concrete also depended upon limestone aggregate size (Yasar *et al.*, 2004). Furthermore the effect of limestone replacement was studies by Bonavetti *et al.* (2003) which revealed that concrete containing limestone powder up to 18 % presented a reduction of compressive strength in the range of 8-12% at 28-day curing time. While Nehdi and Mindess (1996) proposed the effect of replacement of cement with 0-25% limestone powder on the compressive strength of 0.3 – 0.4 w/b ratio super plasticized cement mortars. The findings was in the case the replacement level up to 10-15% by volume there was insignificantly affect the compressive strength of mortar at early ages whereas the replacement level beyond 10-15% caused more significant strength losses. Zhu and Gibbs (2005) studied the use of different limestone in self-compacting concrete (SCC) and found that the fineness of the powder had little effect on the super plasticizer demand and the replacement of cement could be used up to 35% in producing Portland limestone cement and Portland composite cement. Moreover, the compressive strength was significantly greater than that of the conventional concrete mixture at the same w/c ratio, especially at the early ages because it enhanced the rate of cement hydration by filling the pores between cement particles due to the formation of carboaluminate (Heikal *et al*., 2000).

In concrete casting of hollow core slab manufacturing process, the potential filler will be used depending upon the benefits and costs generated by such filler. The hollow core slab factory with capacity of 240,000 ton per year located in the central area of Thailand was selected as a case study. Main direct materials; Portland Cement Type 3, pulverized fuel ash, and aggregate, were mixed together with the proportion of 13:2:85, respectively. Pulverized fuel ash was used as filler for the economic benefits point of view and it had been supplied by electric plant located in the northern of Thailand; approximately 700 kilometer distance, therefore its cost was dominated by transportation cost. According to the oil crisis, its cost was increased drastically. Alternative filler such as limestone power was considered because its supply was available from the cement plants located nearby the case study with lower cost.

The quality of the hollow core slab produced on the average was significantly above standard requirements of the TISI. 828-2003 in which compressive strengths were determined at 300 kg/cm^2 for 1-day curing time or before cutting wire and at 400 kg/cm^2 for 28 days. Decrease in compressive strength value but met the standard requirement was an attractive alternative for the decision maker in cost reduction. In addition, the contemporary economic environments, material costs were accounted for 57:5:38 percent of manufacturing cost, respectively. In other words Portland Cement Type 3 and pulverized fuel ash cost was accounted approximately 62 percent of manufacturing cost which implies that the reduction in such cost could result in significant manufacturing cost reduction as a consequence. Therefore the potential partial substitution of Portland Cement Type 3 by limestone powder was considered as an alternative replacement against pulverized fuel ash. The objective of this study was to conduct the comparative study on the effects of compressive strength between the substitutions of the existing proportion of Portland Cement Type 3 with pulverized fuel ash and with limestone powder in hollow core slab manufacturing process of the selected case study.

2. Experimental Details

2.1 Materials

Portland cement types III according to TISI 15-2003, limestone powder having particle size mean less than 10 micron, and pulverized fuel ash with oxide composition shown in Table 1 were used. Crushed stone and normal river sand were used as aggregate; their physical properties given in Table 2. Tap water was used for the mixing with constant w/b corresponding to the current manufacturing process of the case study.

2.2 Experimental procedure

Experiment with the single factor analysis of variance was designed to evaluate the effects of replacement of cement with pulverized fuel ash and limestone powder with the observed values in terms of compressive strength at 1 day and 28 days. The replacement level of cement with pulverized fuel ash increased from 10% to 15%, 20%, and 25% whereas with limestone powder increased from 5% to 10%, 15%, 20%, and 25%. In order to take the benefits from both fillers, the pulverized fuel ash- limestone powder interaction effect was analyzed by two-factor analysis of variance with the replacement level increased from 10% up to 25% with 5% incremental level. For concrete mixing, the procedure was carried out in accordance to the present manufacturing process of the case study. Cement pastes were mixed subject to the designed replacement levels of the experiments with identical mixing procedure for all the cement pastes. The VEBE test was conducted for cement pastes for each replacement level in accordance to BS1881 Part 104: 1983 to evaluate the slump flow value conforming to the manufacturing requirements; 16-19 cm/30sec.

Table 1: Oxide Composition of Cement, Limestone, and Pulverized Fuel Ash

Chemical property	Cement	Limestone powder	Pulverized fuel ash
Silicon dioxide (% SiO_2)	20.45	0.45	37.51
Aluminium oxide (% Al_2O_3)	5.03	0.20	21.07
Ferric oxide (% Fe_2O_3)	3.12	0.06	13.78
Calcium oxide (% CaO)	63.61	54.58	16.22
Magnesium oxide (% MgO)	1.15	0.73	3.27
Sulfur trioxide (% SO_3)	3.84	-	2.65
Potassium oxide (% K_2O)	0.31	0.01	2.26
Sodium oxide (%Na_2O)	0.25	0.01	1.95
Loss on Ignition (L.O.I)	0.84	43.66	0.07

Table 2: Physical Properties of Aggregate

Aggregate type	Specific surface area (cm^2/kg)		Fineness modulus	
	Requirements*	Experiment value	Requirements*	Experiment value
Crushed stone	4,500-6,000	5,022	5.40-5.49	5.72
Sand	16,000-30,000	17,138	2.15-3.45	3.17

Remark: * means the current requirements in the manufacturing process of the case study.

For each mix, 10 and 6 cube-specimens of size 150 mm. were prepared for main and interaction effect testing, respectively. Half of them were air cure for 1 day and the rest were water-cured for 28 days with curing procedure as in TISI 1736 Part 2-1999. Compressive strength test was undertaken in accordance to TISI 409-2002 with the standard strength values of at least 300 kg/cm^2 and 400 kg/cm^2 for concrete samples at 1 and 28 days, respectively.

3. Results and Discussion

The experimental results were shown in Tables 3. Based on the single factor analysis of variance results shown in Tables 4 and 5 revealed that at 5 % significance level, the replacement levels of cement for both with pulverized fuel ash and with limestone powder significantly affect the 1 day and 28 days compressive strengths whereas the result of two-factor analysis using regression analysis shown in Figure 1 and Table 6 indicated that at 5 % significance level there was no pulverized fuel ash - limestone powder interaction for both 1 day and 28 days compressive strengths. This implied that the replacement of cement with the combination of pulverized fuel ash and limestone powder at the proposed levels could not enhance compressive strength in hollow core slab manufacturing process of the case study. Therefore, using pulverized fuel ash or limestone powder individually was further consideration. In addition, the more the increase in replacement levels, the lower the reduction in compressive strengths was obtained. At the entire proposed replacement levels, the effect of pulverized fuel ash provided higher 1 day and 28 days compressive strength values than of limestone power.

Table 3: Experimental Results of 1 Day and 28 Days Compressive Strength Values

Experiment	Cement	Replacement level (%)		Compressive strength value (kg/cm^2)			
		Limestone powder	Pulverized fuel ash	Day	Observed value	Mean	SD
1	90	-	10	1	443, 412, 419, 423, 422	423.80	11.56
				28	551, 539, 551, 541, 548	546.00	5.66
2	85	-	15	1	402, 426, 368, 375, 372	388.60	24.82
				28	542, 552, 543, 525, 538	540.00	9.82
3	80	-	20	1	365, 363, 336, 346, 336	349.20	14.13
				28	541, 523, 537, 536, 541	535.60	7.40
4	75	-	25	1	325, 286, 284, 293, 295	296.60	16.53
				28	533, 527, 520, 535, 527	528.40	5.90
5	95	5	-	1	401, 434, 385, 390, 381	398.20	21.37
				28	550, 535, 533, 544, 548	542.00	7.65
6	90	10	-	1	365, 384, 345, 338, 334	353.20	20.95
				28	540, 547, 529, 531, 535	536.40	7.27
7	85	15	-	1	346, 328, 324, 306, 332	327.20	14.46
				28	547, 521, 519, 525, 538	530.00	12.04
8	80	20	-	1	309, 308, 294, 301, 309	304.20	6.61
				28	515, 504, 600, 495, 505	503.80	7.40
9	75	25	-	1	285, 298, 270, 263, 268	276.80	14.41
				28	510, 515, 502, 498, 496	504.20	8.08
10	90	5	5	1	385, 350, 351	362.00	19.93
				28	547, 543, 550	546.67	3.51
11	85	10	5	1	324, 322, 330	325.33	4.16
				28	531, 528, 534	531.00	3.00
12	85	5	10	1	336, 317, 329	327.33	9.61
				28	541, 531, 540	537.33	5.51
13	80	5	15	1	318, 296, 293	302.33	13.65
				28	549, 545, 543	545.67	3.06
14	80	10	10	1	299, 281, 326	302.00	22.65
				28	546, 543, 539	542.67	3.51
15	80	15	5	1	326, 304, 333	321.00	15.13
				28	530, 523, 535	529.33	6.03
16	75	5	20	1	270, 284, 298	284.00	14.00
				28	499, 526, 516	513.67	13.65
17	75	10	15	1	271, 293, 284	282.67	11.00
				28	509, 520, 513	514.00	5.57
18	75	15	10	1	300, 282, 275	285.67	12.90
				28	496, 506, 493	498.33	6.81
19	75	20	5	1	250, 267, 262	259.67	8.74
				28	505, 508, 492	501.67	8.51

The relationships between compressive strength and replacement level of cement with pulverized fuel ash and limestone powder were estimated to find out an appropriate replacement levels that generated the compressive strength conforming to the ACI 214R-02.

Table 4: ANOVA-Test between Replacement Levels of Cement with Pulverized Fly Ash

Source	SS	DF	MS	F-test	P-value
1 day:					
Pulverized fly ash	44,709	3	14,903	48.76	<0.001
Error	4,890	16	306		
Total	49,599	19			
S = 17.48 ksc.		Power of test = 0.998		R-sq (adj.) = 88.29 %	
28 days:	1,114.60				
Pulverized fly ash	388.40	3	371.50	15.31	<0.001
Error	1,503	16	24.30		
Total		19			
S = 4.927 ksc.		Power of test = 0.568		R-sq (adj.) = 69.31 %	

Table 5: ANOVA-Test between Replacement Levels of Cement with Limestone Powder

Source	SS	DF	MS	F-test	P-value
1 day:					
Limestone powder	43,374	4	10,843	39.98	<0.001
Error	5,424	20	271		
Total	43,374	24			
S = 16.47 ksc.		Power of test = 0.998		R-sq (adj.) = 86.66 %	
28 days:					
Limestone powder	6,556.2	4	1,639.10	21.78	<0.001
Error	1,504.8	20	75.20		
Total	8,061	24			
S = 8.674 ksc.		Power of test = 0.866		R-sq (adj.) = 77.60 %	

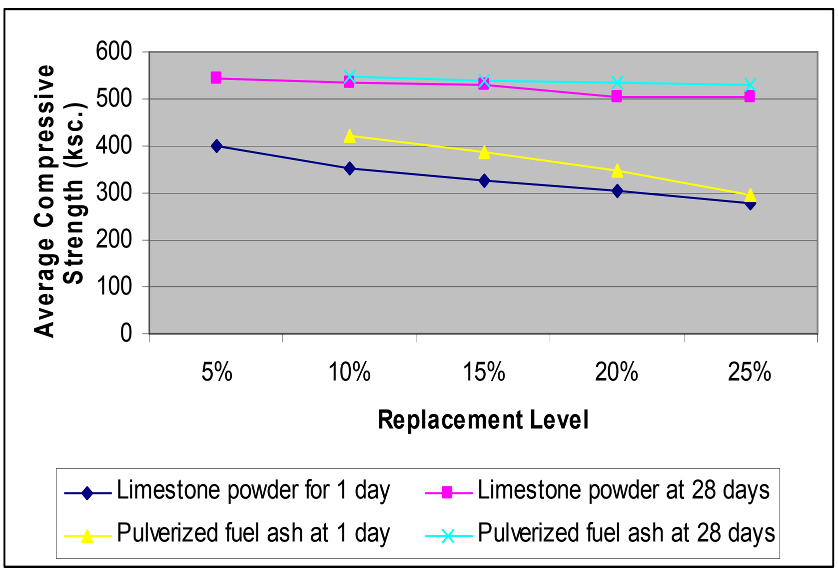

Figure 1: Pulverized Fuel Ash and Limestone Powder Effects at 1 Day and 28 Days Compressive Strength

Table 6: Regression Analysis on Main and Interaction Effects between Replacement Levels of Cement with Pulverized Fuel Ash and Limestone Powder at 1 Day and 28 Days Compressive Strength

Factor	**Effect**	**Coefficient**	**SE**	T-test	P-value
1 day:					
Constant		333.00	3.44	96.89	<0.001
Pulverized fuel ash	-21.33	-10.67	3.44	-3.10	0.02
Limestone powder	-23.33	-11.67	3.44	-3.39	0.01
Pulverized fuel ash * limestone powder	13.33	6.67	3.44	1.94	0.09
S = 11.91	R-Sq (adj) = 66.58 %				
28 days:					
Constant		537.33	1.35	396.85	<0.001
Pulverized fuel ash	-3.00	-1.50	1.35	-1.11	0.30
Limestone powder	-9.33	-4.67	1.35	-3.45	0.01
Pulverized fuel ash * limestone powder	6.33	3.17	1.35	2.34	0.05
S = 4.96	R-Sq (adj) = 58.62 %				

The findings revealed limestone powder and pulverized fuel ash could vary individually with 0-15% and 0-20% by volume; respectively, without any effects to the quality of the product whereas at 28-day curing time the proposed replacement levels gave the compressive strength values above the standard value drastically. Since 1-day compressive strength was the most important factor in hollow core slab manufacturing process on the other hand if the compressive strength of the 1-day curing time met the standard requirement, the 28-day compressive strength would also above the requirement. Therefore, the relationship between 1-day compressive strength and the replacement level of both fillers would be further considered; which was shown in equations (1) to (2) and Table 7.

Compressive strength = 511.9 – 8.42 * % pulverized fuel ash (1)
S = 17.14 ksc. R-Sq(adj) = 88.70 %, Significance F < 0.001

Compressive strength = 419.5 – 5.836 * % limestone powder (2)
S = 16.45 ksc. R-Sq(adj) = 86.71 %, Significance F < 0.001

Table 7: Estimates Interval of the Expected 1-Day Compressive Strength Classified by Replacement Levels

Replacement level (%)	**95% Confidence interval (ksc.)**	**Compressive strength interval classified by filler**	
		Pulverized fuel ash (1)	**Limestone powder (2)**
5	Upper limit	-	***402.11***
	Lower limit	-	***378.53***
10	Upper limit	***441.18***	***369.48***
	Lower limit	***414.23***	***352.80***
15	Upper limit	***394.42***	***338.77***
	Lower limit	***376.78***	***325.15***
20	Upper limit	***352.32***	311.12
	Lower limit	***334.68***	294.44
25	Upper limit	314.88	285.39
	Lower limit	287.93	261.81

For cost analysis, the cost comparison between the options of current replacement level of cement with pulverized fuel ash and with limestone powder at the proposed setting levels was made. The appropriate means of comparison is to compare the relevant costs of the options under consideration. Typically, the relevant costs were direct material costs consisting of cement, filler, and aggregate costs. Based on the existing relevant cost information in 2007, the estimated direct material cost per ton of concrete for the particular material was obtained and shown in Table 8.

Table 8: Estimation of Cost Savings Classified by Replacement Levels

Raw Material (ton)	Cost (Baht/ton)	Current replacement level		Proposed replacement level of cement with							
				Pulverized fuel ash				Limestone powder			
		8%	Cost	15%	Cost	20%	Cost	10%	Cost	15%	Cost
Cement	1774	0.137	243.04	0.116	205.78	0.109	193.37	0.123	218.20	0.116	205.78
Pulverized fly ash	945	0.023	21.74	0.044	41.58	0.051	48.20	-	-	-	-
Limestone powder	350	-	-	-	-	-	-	0.037	12.95	0.044	15.4
Aggregate	184	0.84	154.56	0.84	154.56	0.84	154.56	0.84	154.56	0.84	154.56
Cost per ton of concrete			419.33		401.92		396.12		385.71		375.74

At the present replacement level of cement with pulverized fuel ash at 8% by volume, the analysis revealed the replacement level can be increased up to 20% with the cost savings 17.41 and 23.21 baht per ton of cement or 4,187,961.27 and 5,583,948.36 baht per year, respectively. In the case substitution of pulverized fuel ash by limestone powder, the replacement level could be used up to 15% with the cost savings 43.59 baht per ton or 10,485,901 baht per year which would be an attractive alternative to the decision maker. In addition the evaluation on the uncertainty of the price of limestone powder by performing the sensitivity analysis was conducted. Limestone powder prices were possibly varied at 10 % incremental rate from the base case up to 100%; which was ranging between 350 to 700 baht per ton. The finding indicated that the cost savings of using limestone powder still provided more savings than pulverized fuel ash whether at the 15% or 20% replacement levels.

4. Conclusions

The analysis in this paper based on the experimental result in the laboratory and subjected to the current manufacturing process of the selected case study. The decision on which filler would be used depended on the technical requirements and economic point of view faced by the decision maker. The proposed alternative was to switch from the replacement of cement with pulverized fuel ash to with limestone powder at 15% replacement level without any effects to the quality of the final product and taking the benefit on the significant cost savings.

5. Acknowledgement

The authors would like to express their sincere gratitude to the selected case study for all the necessary laboratory equipment and the technical support.

6. References

ACI Committee 214. (2002). *Evaluation of Strength Test Results of Concrete*, ACI 214R-02. pp. 20.

Bonavetti, V., Donza, G., Menendez, O., Cabrera, O., and Irassar, E.F. (2003). "Limestone filler cement in low w/c concrete: a rational use of energy". *Cement and Concrete Research*, Vol. 33, pp. 865-871.

British Standards Institute. (1983). *Method of Determination of VEBE Time*, BS 1881: Part 104.

Heikal, M., El-Didamony, H., and Morsy, M.S. (2000). "Limestone-filler pozzolanic cement". *Cement and Concrete Research*, Vol. 30, pp 1827-1834.

Nehdi, M., and Mindess, S. (1996). "Optimization of high strength limestone filler cement mortars". *Cement and Concrete Research*, Vol. 26, No. 6, pp. 883-893.

Thai Industrial Standards Institute. (2004). *Portland Cement Part 1 Specification, TISI 15-2004.*

Thai Industrial Standards Institute. (2002). *Test method for compressive strength of concrete specimens, TISI 409-2002.*

Thai Industrial Standards Institute. (2003). *Precast prestressed concrete elements for composite floor systems TISI 828-200.*

Thai Industrial Standards Institute. (1999). *Concrete tests - test specimens - Part 2: Making and curing of test specimens for strength tests TIS 1736 Part 2-1999.*

Tsivilis, S., Batis, G., Chaniotakis, E., Grigoriadis, Gr., and Theodossis, D. (2000). "Properties and behavior of limestone cement concrete and mortar". *Cement and Concrete Research*, Vol. 30, pp. 1679-1683.

Tsivilis, S., Chaniotakis, E., Kakali, G., and Batis, G. (2002). "An analysis of the properties of Portland limestone cements and concrete". *Cement & Concrete Composites*, Vol. 24, pp. 371-378.

Yasar, E., Erdogan, Y., and Kilic, A. (2004). "Effect of limestone aggregate type and water-cement ratio on concrete strength". *Material Letters*, Vol. 58, pp. 772-777.

Zhu, W., and Gibbs, J. C. (2005). "Use of different limestone and chalk powders in self-compacting concrete". *Cement and Concrete Research*, Vol. 35, pp. 1457-1462.