Development of Lightweight Aggregate Concrete Containing Pulverized Fly ash and Bottom Ash

Theradej Litsomboon[1, a], Pichai Nimityongskul[2,b] and Naveed Anwar[3,c]

[1] Master in Structural Engineering, School of Engineering and Technology, Asian Institute of Technology, P.O. Box 4, Klongluang, Pathumthani 12120, Thailand

[2] Associate Professor, Structural Engineering Field of Study, School of Engineering and Technology, Asian Institute of Technology, P.O. Box 4, Klongluang, Pathumthani 12120, Thailand

[3] Director, Asian Center for Engineering Computations and Software (ACECOMS), Affiliate Faculty, Structural Engineering Field of Study, Asian Institute of Technology, P.O. Box 4, Klongluang, Pathumthani 12120, Thailand

[a]st104798@ait.ac.th, [b]pichai@ait.ac.th, [c] nanwar@ait.ac.th

Keywords: lightweight aggregate, lightweight aggregate concrete, bottom ash, fly ash, compressive strength, density, absorption, abrasion resistance.

Abstract. This study examines the feasibility of using different lightweight aggregates (LA) and bottom ash as coarse and fine aggregates in concrete with fly ash. The lightweight materials were composed of 3 types, namely pumice, cellular lightweight aggregate and MTEC lightweight aggregate. The tests for physical and mechanical properties of lightweight aggregate concretes (LWAC) were conducted in terms of workability, compressive strength, apparent density, abrasion resistance and absorption. Test results showed that compressive strength of LWAC increased with an increase in apparent density, which is mainly depending on the type of aggregate. The replacement of normal weight sand with bottom ash resulted in a decrease both in density of concrete by 180-225 kg/m^3 and 28-day compressive strength of concrete by 16-26%. Moreover, the use of bottom ash to replace sand in concrete increased the demand for mixing water due to its porosity and shape and to further obtain the required workability. The type and absorption of LA influenced predominantly the water absorption of LWAC. Total replacement of natural sand by bottom ash increased the absorption of the concrete by 63-90%. With regard to abrasion resistance, the abrasion resistance of lightweight aggregate concrete was mainly dependent on the compressive strength of concrete: the higher the strength, the higher the abrasion resistance of LWAC. In addition, the use of bottom ash as a fine aggregate resulted in a lower abrasion resistance of lightweight aggregate concrete due to its porosity. Of the three types of lightweight materials, MTEC LA had achieved both low density and high compressive strength.

Introduction

Nowadays, lightweight concrete (LWC) is gaining widespread popularity in the global market. This type of concrete has a number of advantages i.e., less requirement of structural steel reinforcement, smaller size of column, footing and other load bearing elements. Several methods have been developed to produce LWC of which the use of lightweight aggregate (LA) is commonly employed. Such aggregates, natural or artificial, are available in many parts of Thailand, and can be used in producing concrete in a wide range of unit weights and suitable strength values for different fields of applications.

Some researchers have attempted to conduct a feasibility study on the use of waste materials as fine and coarse aggregate in the production of LWAC. Also, several studies [1-5] have focused on the use of bottom ash in place of normal weight sand in concrete. It was found out that bottom ash could be a potential fine aggregate in normal-weight and lightweight concrete, however, the compressive strength of concrete had decreased with an increase in the replacement level of natural sand with the bottom ash. Moreover, related studies [3, 4] revealed that bottom ash causes detrimental effect on the permeability of concrete. On the contrary, fly ash is able to improve the permeability concrete, however, the strength decreases.

In this study, replacement of cement in the mix using residue from the combustion of coal in power generation industry, fly ash and bottom ash was hypothesized. Expected output aims to help in alleviating the problem on industrial waste disposal and reduction of LWAC's initial cost. Overall, this study presents experimental results of using waste materials such as fly ash and bottom ash and different lightweight materials available in Thailand as fine and coarse aggregates as replacement materials in order to produce LWAC.

Experimental Program

Material. Ordinary Portland Cement (OPC) Type I was used throughout the whole testing program. Fly ash and bottom ash were obtained from the Mae Moh Lignite Power Plant in Lampang Province of Thailand. The details of chemical compositions of fly ash and bottom ash are presented in Table 1. River sand and bottom ash, passing standard sieve No.8, were used in mix proportions as fine aggregate.

Table 1. Chemical Composition of Fly Ash and Bottom Ash

Oxides	Oxide Composition [%wt]	
	Fly Ash	Bottom Ash
Na_2O	1.98	0.56
MgO	2.99	1.28
Al_2O_3	20.95	14.77
SiO_2	36.38	25.05
SO_3	1.44	2.37
K_2O	2.25	2.28
CaO	19.68	14.05
TiO_2	0.33	0.39
MnO	-	0.1
Fe_2O_3	13.65	10.47
Traces	0.35	28.68
Total	100	100
Loss of Ignition (LOI)	0.09	-

Lightweight materials consist of pumice, cellular LA and MTEC LA. Pumice was a natural sponge-like material of volcanic origin, composed principally of silica and produced from molten lava rapidly cooling and trapping millions of tiny air bubbles. Cellular LA was a crushed lightweight cellular concrete block while MTEC LA is a light, porous and a manufactured material. The latter is based on the utilization of non-hazardous waste developed by the Ecocera team, National metal and Materials Technology Center (MTEC), Thailand. All LA in this study having a nominal maximum size of 12.5 mm was used as a lightweight coarse aggregate replacing crushed lime stone in concrete. Various physical properties of different types of LA are shown in Table 2.

Mix proportions. The testing was divided into two parts. In the first part, fly ash was used to replace 25% of the weight of cementitious materials, and natural river sand was used as fine aggregate (binder: sand ratio = 1: 2.25). The cementitous material was 335 kg/m^3 with water binder ratio (*w/b*) of 0.4 kept constant for all mixes. It should be noted that the dosage of superplasticizer, which was based on poly-carboxylic ether (PCE), was set in varied amounts for the sake of consistency in all mixes. Due to high absorption rate prior to casting of concrete, the aggregate was made saturated surfaced dry (SSD) by immersing it under water for 24 hours. Cube specimens with dimensions of 10 x 10 cm were cast from fresh concrete mixture. The compaction of samples was done using a vibrating table. All the specimens were demoulded for 1 day and were cured under water in the curing room until the time of testing.

Table 2. Physical Properties of Lightweight Aggregates

Properties	Pumice	Cellular LA	MTEC LA
Bulk Specific Gravity (SSD)	1.13	1.25	0.87
Absorption (%)	53.13	32.49	9.91
Fineness Modulus	7.25	6.22	7.60
Maximum Size (mm)	19.00	9.50	19.00
Elongation Index (%)	11.60	8.33	6.46
Flakiness Index (%)	7.20	36.37	0.62

For the second part, bottom ash was used as fine aggregate to replace the river sand. In order to study the water requirement of all-lightweight concrete in terms of workability, dosages of superplasticizer were kept constant in the first part while *w/b* ratio was set in varying quantity. The weight of cementitous material and percentage of fly ash replacement were the same with the first part. This was done by controlling the amount of water used in each mix.

The specimens were cast to determine the compressive strength, apparent density, abrasive resistance test and absorption. For compressive strength and apparent density, 10-cm cube specimens were cast and tested at 7 and 28 days. The abrasive resistance of 15-cm cube lightweight aggregate concretes was tested at 28 days using the Rotating-Cutter Method. The 10-cm cube lightweight aggregate concretes were tested for absorption at 28 days. All tests were carried out in accordance with ASTM and British Standards. The details of mix proportions are shown in Table 3.

Table 3. Mix Proportion of Lightweight Aggregate Concrete

Mixes	Type of LA	Mixture Proportion [kg/m^3]					
		Cement	Fly Ash	Sand	Bottom Ash	LA	w/b
MFP	Pumice	251.25	83.75	753.75	-	476.09	0.4
MFS	Cellular LA.	251.25	83.75	753.75	-	517.38	0.4
MFM	MTEC LA.	251.25	83.75	753.75	-	366.48	0.4
MFBP	Pumice	251.25	83.75	-	391	476.09	Vary
MFBS	Cellular LA.	251.25	83.75	-	391	517.38	Vary
MFBM	MTEC LA.	251.25	83.75	-	391	366.48	Vary

The percentage of superplasticiser, *w/b* ratio, air-dry density, compressive strength, weight loss and water absorption of LWAC containing fly ash and bottom ash are given in Table 4.

Table 4. Mechanical and Physical Properties of Lightweight Aggregate Concrete

Mixes	Percentage of Superplasticiser	w/b	Air-Dry Density [kg/m^3]	Compressive Strength [ksc]		Weight Loss [g]	Water Absorption [%]
				7 days	28 days		
MFP	5.0%	0.4	1727.35	140.51	159.35	16.4	18.50
MFS	4.0%	0.4	1729.88	156.66	178.89	14.6	13.82
MFM	3.0%	0.4	1638.25	213.65	236.25	9.4	8.76
MFBP	5.0%	0.6	1501.19	98.89	129.85	19.2	30.13
MFBS	4.0%	0.64	1550.39	98.13	132.68	15.0	24.90
MFBM	3.0%	0.61	1410.93	150.13	199.13	12.6	16.67

Results and Discussion

Workability. In the case of all-lightweight concrete (MFBP, MFBS and MFBM) where the dosage of superplasticizer was kept constant, the water requirement had increased just to maintain the desired workability. This is due to the fact that bottom ash used in the mix is a fine porous material capable of retaining more water and having high absorption rate while its angular shape causes higher friction during the mixture.

Air-Dry Density. For the comparisons of air-dry density between sand-lightweight and all-lightweight concrete, shown in Table 4, it is interesting to note that when natural sand was replaced with bottom ash, there was a significant reduction in the density of hardened concrete. This suggests that bottom ash is advantageous in producing LWAC. The complete replacement of natural sand with bottom ash had decreased the density of concrete by 180-225 kg/m^3.

Compressive Strength. In the case of sand-lightweight concrete, it was observed that LWAC containing MTEC LA has the highest compressive strength of 236 ksc (23.14 MPa) at 28-day. On the other hand, the LWAC prepared with pumice had the lowest compressive strength of 159 ksc (15.59 MPa). When only the type of aggregate was changed while the other components such as binder (cement and fly ash) content, fine aggregate and *w/b* were kept constant, it can be concluded that the type of lightweight aggregate was the main factor affecting the compressive strength of LWAC.

In the case of all-lightweight concrete, results showed that the compressive strength of all lightweight aggregate concrete using bottom ash as fine aggregate was lower than that of sand-lightweight concretes. The 28-day compressive strength was reduced by 18.5% (using Pumice), 25.8% (using Cellular LA) and 15.7% (using MTEC LA) compared with the sand-lightweight concrete. Thus, the use of bottom ash as fine aggregate resulted to a decrease in compressive strength of concrete. However, it was observed that the LWAC containing bottom ash considerably decreased in compressive strength. Further, results showed that the use of bottom ash replacing river sand in concrete was able to reduce both density and the compressive strength of concrete.

The air-dry densities of LWAC made with pumice, cellular LA and MTEC LA had satisfied the criteria for structural low-density (lightweight) concrete having a density of less than 1850 kg/m^3. However, only MTEC LA concrete satisfied the criteria of structural lightweight concrete as per ACI 213R, which requires minimum 28 day compressive strength of 17 MPa and maximum air dry density of 1850 kg/m^3.

Abrasion Resistance. In the case of sand-lightweight concrete, the concrete containing pumice was found to have the highest value of weight loss among the three types of lightweight aggregate being used, which was 16.4 g as shown in Table 4. On the contrary, concrete containing MTEC LA yielded the minimum value of weight loss, which was 9.4 g. Similar result was found in the LWAC using bottom ash as fine aggregate.

In the comparison of weight loss between using normal sand and bottom ash as fine aggregate in LWAC, results showed that the abrasion resistances of concrete using sand as fine aggregate were higher than those of all-lightweight aggregate concrete. It was further observed that the use of bottom ash as fine aggregate resulted in a lower abrasion resistance of LWAC.

It is interesting to note that the increase in compressive strength of concrete appears to be directly related to the decrease in weight loss of concrete, as shown in Fig. 1. Thus, the abrasion resistance increased as compressive strength increases.

Absorption. Water absorption of three types of LA namely pumice, Cellular LA and MTEC LA, and LWAC containing such aggregates with sand and bottom ash as fine aggregate was investigated, as shown in Fig. 2. The test results revealed that water absorption of concrete was found to vary with water absorption of LA, as expected.

Moreover, there was an increase in the water absorption of concrete when natural sand was replaced with bottom ash as fine lightweight aggregate. The absorption of LWAC was increased by 62.9% (using Pumice), 80.2% (using Cellular LA) and 90.3% (using MTEC LA) compared with sand-lightweight concrete. The result further emphasized that water absorption of lightweight aggregates concrete is dependent on the types and absorption of LA.

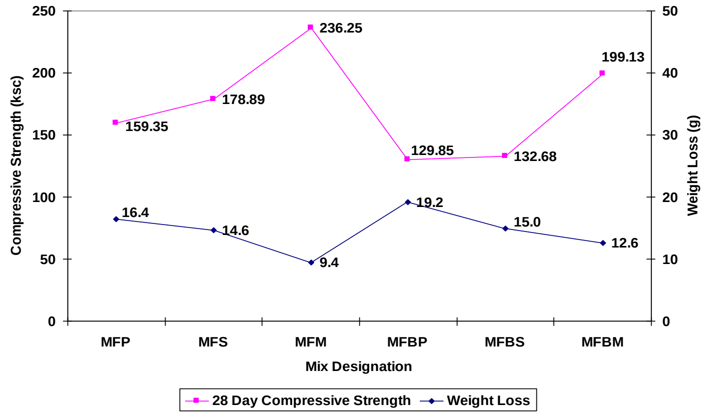

Figure 1. Relationship between Compressive Strength and Weight Loss

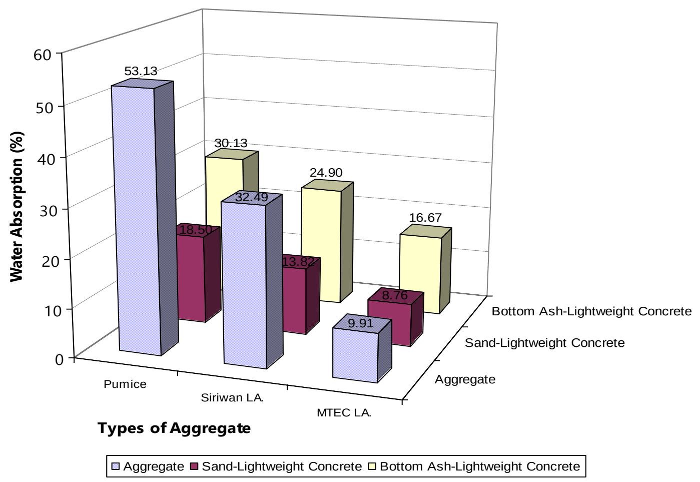

Figure 2. Water Absorption of LA, Sand-LWC and Bottom Ash- LWC

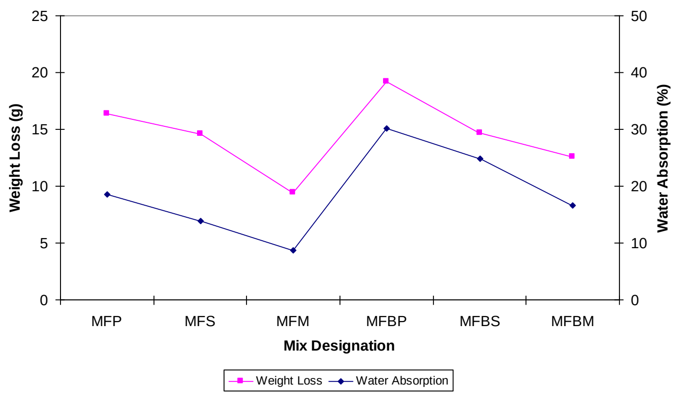

Figure 3. Relationship between Weight Loss and Water Absorption

The relationship between weight loss and water absorption of concrete containing different LA is shown in Fig. 3. The graph shows similar to that of weight loss of LWAC. It is therefore possible to conclude that high water absorption of concrete caused a reduction in the abrasion resistance.

Summary

Based on the laboratory test results, the following conclusions were drawn:

1. MTEC LA had achieved both low density and high compressive strength. Although pumice and Cellular LA had disadvantages in compressive strength, the criteria for low-density concrete were satisfied.
2. The main key factor affecting the compressive strength of LWAC was the type of LA used. In addition, the compressive strength was directly proportional to the air-dry density of hardened concrete.
3. The replacement of normal weight sand with bottom ash had resulted in the decrease of both density of concrete and 28-day compressive strength of concrete by 180-225 kg/m^3 and 16-26%, respectively. Moreover, the use of bottom ash to replace sand in concrete increased the demand for mixing water to obtain the required workability due to its porosity and shape.
4. The type and absorption of LA influenced predominantly the water absorption of LWAC. Total replacement of natural sand by bottom ash increased the absorption of the concrete by 63-90%. Relatively, an increase in absorption of concrete resulted in a lower compressive strength and abrasion resistance.
5. With regards to abrasion resistance, the abrasion resistance of LWAC was mainly dependent on the compressive strength of concrete: the higher the strength, the higher the abrasion resistance of LWAC. However, high water absorption of concrete caused a reduction in the abrasion resistance. In addition, the use of bottom ash as a fine aggregate resulted in a lower abrasion resistance of LWAC due to its porosity.

References

[1] P. Aggarwal , Y. Aggarwal and Gupta S.M: *Effect of Bottom Ash as Replacement of Fine Aggregate in Concrete*, Asian Journal of Civil Engineering (Building and Housing) Vol.8, No.1 (2007), pp. 49-62

[2] A.A. Al-Rawas, A.W. Hago, R. Taha and K. Al-Kharousi: *Use of Incinerator Ash as a Replacement for Cement and Sand in Cement Mortars*, Building and Environment 40 (2005) , pp.1261–1266

[3] Y. Bai and P.A.M. Basheer: *Influence of Furnace Bottom Ash on properties of concrete*, Proceedings of the Institution of Civil Engineers, Structure and Buildings 156, Issue 1 (2003), pp. 85-92

[4] Y. Bai, R. Ibrahim and P.A.M. Basheer: *Properties of Lightweight Concrete Manufactured with Fly Ash*, Furnace Bottom Ash, and Lytag, International Workshop on Sustainable Development and Concrete Technology (2003).

[5] K. Pakinaga: *Use of Bottom Ash as Fine Aggregate in Concrete*, M.S. Thesis, Asian Institute of Technology, Bangkok (1999).

[6] X.C. Qiao, B.R. Ng, M. Tyrer, C.S. Poon, C.R. Cheeseman: *Production of Lightweight Concrete Using Incinerator Bottom Ash*, Construction and Building Materials, Elsevier Ltd., 2006, in press.

[7] Information on http://www.mtec.or.th/th/special/ecocera/index.html