Fourth International Conference on Sustainable Construction Materials and Technologies
http://www.claisse.info/Proceedings.htm

SCMT4
Las Vegas, USA, August 7-11, 2016

Applicability Evaluation of Ponded Ash as a Sustainable Backfill Material Using Air Foam

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ABSTRACT

This study presents the research results on applicability of ponded as backfill materials using air foam technology. The objective of this study is to recycle as much as ponded with smaller amount of cement quantity using air foam. Various ponded ash contents (0, 30, 60, 100%), various cement contents (30, 60, 90kg/m3), and two different air foam contents (15 and 20%) were used to make specimens and test to evaluate the applicability as backfill materials. For comparison purpose, 0% ponded ash means that 100 % of construction sand was used. For all the combinations of backfill materials, flow was measured to see if their values meet the minimum flow value which is 200mm. The specimen size is 70mm in diameter and 140mm in length which is made by PVC pipe. All the specimens were cured in 100 % moisture condition and tested by uniaxial compressive strength test after 28day curing. Also, leaching test was conducted to evaluate toxicity in ponded ash and specimens, and salt concentration analysis was performed on ponded ash to evaluate the availability as construction materials.

The test results showed that toxicity and salt concentration were far below from the limitation. In terms of 28 day cured compressive strength, strength was increased as ponded ash and cement contents increased. For Asphalt Concrete Institute and Federal Highway Administration standards of backfill materials which are 0.5-1.0 MPa for 28day compressive strength, 100% ponded ash and 60kg/m^3 cement content with 15 % air foam meet the strength and flow standards.

INTRODUCTION

In recent years, there have been significant efforts in utilizing various industrial by-products in the production of many construction materials. With the subject of by-product development, several promising studies have been published such as utilization of red mud derived from bauxite in self-compacting concrete [Liu and Poon 2016], analysis of fly ash cement concrete for road construction [Tomas and Ganiron 2013], development of self-compacting concrete by using high volume of calcareous fly ash [Papayianni and Anastasiou 2011], the application of the ponded coal ash as construction materials [Hwi et at., 2011]. The production of ash from power plants stations has increased millions tonnes year by year. In wet disposal system, the bottom ash from the boilers and the fly ash from the precipitators are mixed together and pumped off in the form of slurry to lagoons, where water is drained off or recycled. This mix is defined as ponded ash which is classified as a waste by-product material [Do et al., 2015]. However, it is mostly not recycled as fly ash but is ponded entirely. If the ponded ash is not managed accurately, there will be serious problems due to the storage of waste and potential impact to the environment. Accordingly, it is desperately needed to develop diverse construction materials which can consume ponded ash in a large scale [Hwi et al., 2011]. In addition, reducing the demand on landfill (construction sand) will contribute towards the sustainable development. This has led to the potential concern of identifying new sources of fine aggregate. Hence, the possibility of utilization ponded ash as replacement to the construction sand in backfill materials is the main aim in this research.

This study presents the experimental investigation in the new development of air foam backfill materials using ponded ash. Several mixtures were tested to evaluate the combine use of ponded ash and construction sand in backfill materials manufacture, 4 different ratios of sand (S) and ponded ash (PA) content were make as fine aggregate: (100% S – 0% PA, 70%S – 30%PA, 40%S – 60%PA, 0%S – 100%PA). In addition, there are 3 conditions of cement contents (30 kg/m^3, 60 kg/m^3, 90 kg/m^3) and 2 conditions of air foam contents (15 and 20 %). In this research, there are two main states which were conducted to analyse the applicability of ponded as backfill materials. In state 1, optimum mix proportion was figured out by initial flow test [ASTM D6103] in fresh state. State 2 focused on determine the hardening process by penetration test [ASTM C403] and unconfined compressive strength of the specimens after 28 days curing.

EXPERIMENTAL INVESTIGATIONS

Material. Portland cement type I was used in this study. Ponded ash was obtained from the wastes storage operated by Korea Western Power Plant Corporation, Korea. The ponded ash contained different size from fine powder to nearly 10mm (figure 3(a)). The grading curve for bottom ash is shown in figure 1.

Table 1. Material properties

Material	Description
Portland cement	ASTM C150 Type I (Specific gravity = 3.15 g/cm^3)
Ponded ash	Specific gravity = 2.1 g/cm^3, moisture content: 22%
Construction sand	Specific gravity = 2.6 g/cm^3, moisture content: 7%
Chemical admixtures	Air foam (liquid)

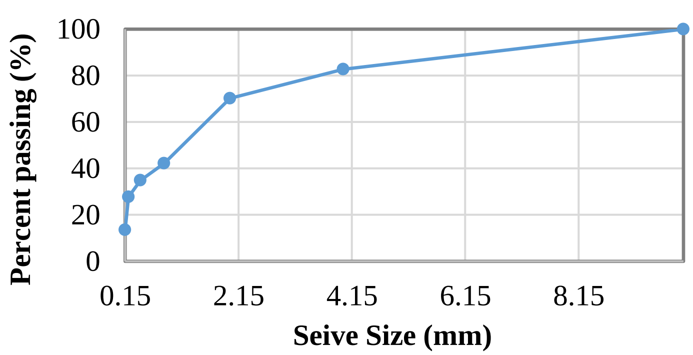


Figure 1. Grading curve of Ponded Ash

Mix proportion. The mix formulation used in this study are described in Table 2 and 3. Air foam was prepared using a foaming agent mixed with water. The optimal ratio between foaming agent and water was 1:20 and they were mixed thoroughly in the air foam mixing device with careful control of air pressure in order to get a homogeneous air foam mixture. The density of air foam was controlled at 0.047 g/cm^3 [Park and Vo 2014]. Fine aggregate, ponded ash, and cement were first mixed with approximately half of the expected mixing water for 2 minutes, followed by 1 minutes of rest period. The remainder water and prepared air foam were then added and mixed for additional 3 minutes [NCHRP 597]. After a thorough mixing, the slurry was cast into specimens in the PVC pipe moulds which have 150mm in height and 150mm in diameter for the penetration test. The same preparation was performed for flow test and unconfined compressive test, but the moulds were 140-mm height and 70-mm diameter.

Table 2. 15% air foam mix formulations.

Mix	**Cement**	**Ponded ash**	**Sand**	**Air foam**	**Water**
	Kg/m^3	Kg/m^3	Kg/m^3	L	Kg/m^3
0PA30a*	30	0	1577	150	212
0PA60a	60	0	1536	150	200
0PA90a	90	0	1527	150	162
30PA30a	30	446	1041	150	170
30PA60a	60	439	1025	150	156
30PA90a	90	426	994	150	127
60PA30a	30	850	566	150	135
60PA60a	60	834	556	150	118
60PA90a	90	817	544	150	90
100PA30a	30	1358	0	150	30
100PA60a	60	1292	0	150	60
100PA90a	90	1226	0	150	90

**0PA30a = 0% Ponded ash - 100% sand 30kg/m^3 cement and 15% air foam.*

Table 3. 20% air foam mix formulations

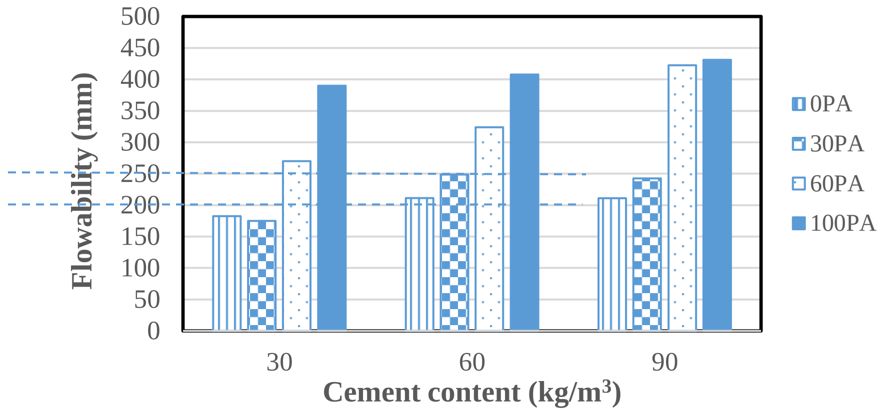
Mix	Cement	Ponded ash	Sand	Air foam	Water
	Kg/m^3	Kg/m^3	Kg/m^3	L	Kg/m^3
0PA30b	30	0	1479	200	212
0PA60b	60	0	1437	200	200
0PA90b	90	0	1423	200	162
30PA30b	30	419	977	200	170
30PA60b	60	411	958	200	156
30PA90b	90	397	926	200	127
60PA30b	30	797	531	200	135
60PA60b	60	780	520	200	118
60PA90b	90	761	507	200	90

**0PA30b = 0% Ponded ash-100% sand, 30kg/m^3 cement and 20% air foam.*

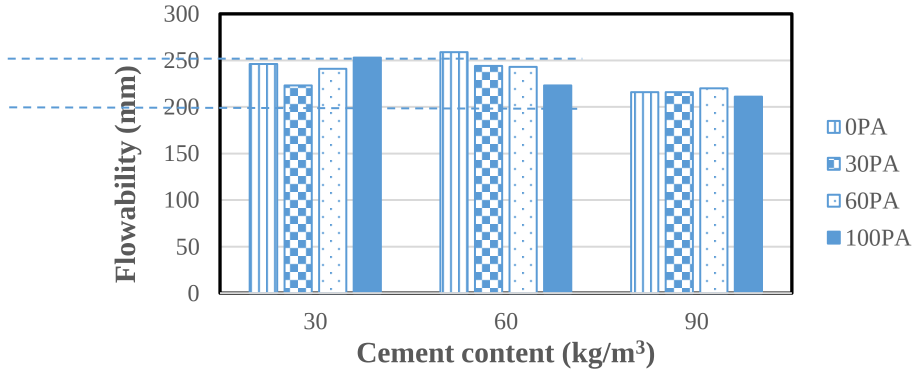
RESULTS AND DISCUSSIONS

Flowability. Flowability is the mechanical property which is a major advantage that distinguish backfill materials from other fill materials [ACI 229R]. In this research, the flow test was conducted in accordance with ASTM D6103. After well mixing, the paste was filled to a 70 x 140mm open-ended cylinder held firmly in steel plate. Then, the cylinder was raised up vertically and gradually in 3s and the largest spread diameter (like a pancake) was measured. The initial mixture proportion was kept if the sample spread diameter is between 200 and 250mm with no sign of segregation (figure 3(b)). If the diameter was less than 200mm, more water should be added until reaching the desirable flowability. The amount of added water was then recorded to modify the mixture proportion.

Figure 2a shows the initial flow test values of all mixed, ranging from 175mm to 430mm. Mixtures of 100% sand showed relatively low flow value (varied from 183 to 211 mm). Hence, in mixture of high sand content, more water was included to achieve optimum flowability. The higher ponded ash content was added (30PA, 60PA, 100PA), the higher flowability level of the mixture was reached (approximately 216mm, 374mm, 409mm, respectively). The result showed that the flowability was effected significantly by the fine aggregate proportion. As shown in figure 2(b), final formulation was set out and they almost all showed perfect flowability due to the benefit of initial test, ranging from 211 to 259mm.



(a)



(b)

Figure 2. Flow test results of backfill materials specimens at 15% air foam: (a) in the trial mixtures, (b) in final mixtures.

(a) (b) (c) (d)

Figure 3. (a) Ponded ash; (b) Flow test; (c) Penetration test; (d) Unconfined compressive strength test

Setting Time. Needle penetration was used to measure the hardening process of backfill material [ASTM C403] (figure 3(c)). The test was performed after 4 - 5 hours after the first contact between cement and water. Depth of penetration was 25mm. As determined in related researches, the time required for the samples to reach 2.74 MPa of resistance to penetration were used to define time of setting [Kuo and Wang 2013].

Figure 4 demonstrates the setting time of all backfill material mixtures, varied from 13 to 93 hours. The mixture with 90 kg/m^3 cement and 100% ponded ash had fastest setting time within 13 hours. The higher cement content was added, the faster target setting time was achieved. For examples, when the cement content increased from 30 to 60 kg/m^3, the setting time reduced remarkably from 93 to 36 hours with those 60PA mixtures. Hence, more cement can be added to prevent a long setting time.

Moreover, the setting time of samples was also reduced by ponded ash content. For a constant cement content of 60 kg/m^3, the setting time was decrease from 84 to 18 hours when ponded ash content increased from 0 to 100%.

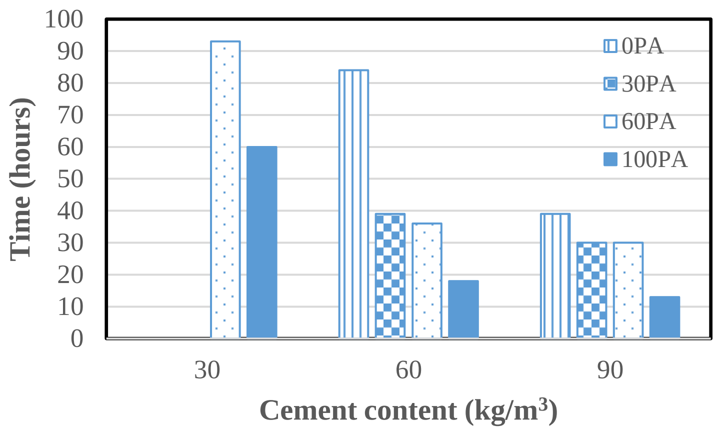
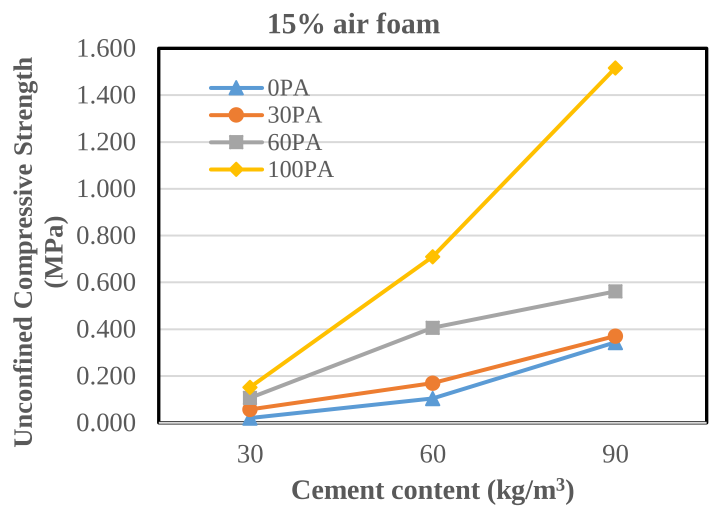


Figure 4. Penetration test result of backfill material mixtures at 15% air foam

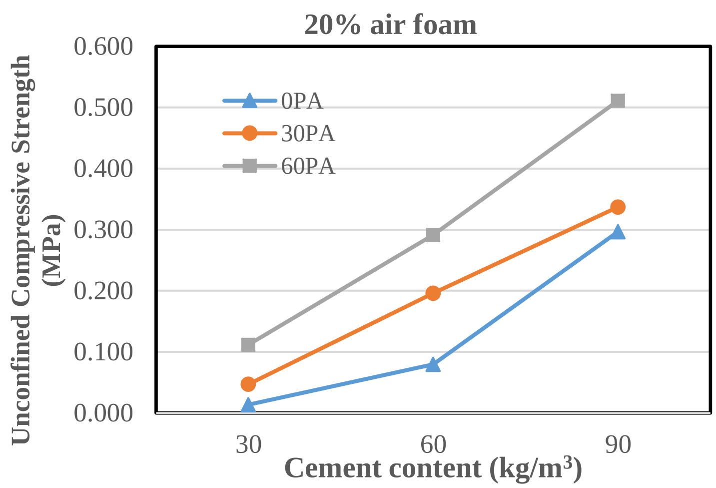
Unconfined compressive strength. The unconfined compressive strength test was conformed to ASTM D4832. Regarding curing condition, after 7 days of 100% moist-curing in room temperature at 23°C, all the specimens were demoulded and carefully stored in the same curing condition until the test day. Testing machine capacity was 50kN and loading rate was kept low at 1 mm/min. It will enable the test to be more accurate due to low-strength material specimens. Then, all dimensions of specimens were measured and the test was conducted. Each strength test was done on three cylinders and then the averages were obtained (figure 3(d)).

As regards the first from Figure 5a, those samples with 30 kg/m^3 cement content showed relatively weak compressive strength, ranging from 0.02 to around 0.15 MPa. This result is much lower than bearing pressure requirement for backfill material in this study target. In fact, those specimens were damaged by curing condition. It can also be seen that group specimens with 90 kg/m^3 cement content accounted for the highest compressive strength. The increase in strength was more pronounced when more sand was replaced by ponded ash content. For examples, mixture with 90 kg/m^3 cement content exhibited enormous strength gain compared to mixes 60PA, 30PA and 0PA (1.81, 0.56, 0.37 and 0.34 MPa, respectively). This may be due to the higher rate of cement hydration with the presence of ponded ash. Especially, mixture containing 100% ponded ash, 60 kg/m^3 cement and 15% air foam were the mixture that satisfied the target strength (0.93 MPa).

In terms of air foam content, the samples with 15 % air foam had higher strength than the ones with 20 % air foam. It demonstrated that the more air foam is included, the more the unconfined compressive strength is dropped (figure 5).



(a)



(b)

Figure 5. The effect of cement content and ponded ash to the unconfined compressive strength. (a) at 15% Air foam; (b) at 20% air foam.

Leaching. When applying ponded ash as a replacement for construction sand in backfill materials, some important concern of leaching property and its effect to environment must be taken into account. The leaching test method was conformed to TCLP [EPA Method 1311]. Leachate samples were analysed for 7 heavy metal: Cadmium, Copper, Nickel, Lead, Zinc, Arsenic, Mercury. The limits given in Table 5 are based on leaching test recommended acceptance criteria for suitability of industrial wastes for landfill disposal. In Lead and Arsenic metal tests, the results were far lower than the limits, approximately 150 and 300 times lower, respectively. In addition, there was no sign of Cadmium, Copper, Nickel and Zinc. Regard to salt concentration analysis, all samples showed acceptable salinity value, ranging from 0.51 to 1.32%. Thus, the ponded ash is categorized non-toxicity and suitable for use as backfill materials.

Table 5. Results of leachable substances

Elements	Cd (mg/L)	Cu (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)	As (mg/L)	Hg (mg/L)
Designated Hazardous Waste Materials Containing Criteria (mg/L)	<0.3	<3	-	<3	-	<1.5	<0.005
A-1	0.000	0.000	0.000	0.02	0.000	0.005	0.00
A-2	0.000	0.000	0.000	0.02	0.000	0.007	0.00
A-3	0.000	0.000	0.000	0.02	0.000	0.003	0.00

Table 6. Results of salt concentration analysis

Sample	Distilled water (mL)	Soil Weight (g)	Measurements (ms/cm)	Temperature correction factor	EC (dS/m)	% Conversion Factor	Salinity (%)
A-1	50.012	10.497	3.884	1.112	20.578	0.064	1.3170
A-2	50.693	10.731	2.149	1.112	11.289	0.064	0.7225
A-3	50.477	10.264	1.458	1.112	7.973	0.064	0.5103

CONCLUSION

This paper discussed the viability of using ponded ash in the production of backfill materials. The following conclusion can be drawn from this study:

- An increase in ponded ash content decreases the water demand for backfill materials mixture to meet appropriate flow value.
- The setting time was shortened by the enhancement of cement in the production of ponded ash-backfill materials. Strength development was also faster with the increase in ponded ash content.
- The 28-day compressive strength of backfill material mixtures is in the range of 0.014 and 1.51 MPa. The higher ponded ash and cement content was added the higher compressive strength of the sample was achieved.
- Mixture 100PA60a produced with 100% ponded ash, 60 kg/m^3 cement content and 15% air foam obtained this study target in both fresh state (flowability = 221mm) and hardened state (compressive strength = 0.931 MPa).

- The leaching test and salt concentration analysis results are far lower than the limiting criteria which indicates that ponded ash is a feasible "by-product" material for backfill materials manufacture.

ACKNOWLEDGMENT

The authors would like to thank the Korea Western Power Plant Corporation for the financial support.

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