

Development of ECO Block with Rainwater Management Ability

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ABSTRACT: Permeable pavement systems are suitable for a variety of residential, commercial and industrial applications, yet are confined to light duty and infrequent usage. And Most of study for the permeable pavement is limited to asphalt pavement. Also, immense quantities of coal combustion by-products are produced every year, but only a small fraction of them are currently utilized, particularly bottom ash which is used in this study.

So, the purpose of this study is to investigate reused techniques of coal ash in the construction field and to measure thermal environment characteristics and capability of pollution control of permeable pavement block with coal ash.

In this study, mechanical characteristics-compressive strength, porosity etc were carried out. Experiments for thermal environment characteristics and pollution control were carried out in laboratory scale using modified pavement samples. Solar-reflective paints as well as synthetic polymers were used to provide solar-reflective layer on the surface of pavement samples. The area of pavement samples were 50 x 50 cm. Eight halogen lamps (each lamp is 500 W) were used to simulate natural solar radiation. A heat-image camera and a temperature sensor were used to monitor the changes in temperature during the experiments

Keywords: Bottom ash, Block, Rainwater, Permeability, Decontamination

NOMENCLATURE

BA : Bottom ash

BB : Bottom ash Block

BBPM : Bottom ash Block with Peat Moss

FW : Rainwater on the road

BBW: Rainwater of runoff though bottom ash block

BBPMW: Rainwater of runoff though bottom ash block with peat moss

1. INTRODUCTION

An urban heat island (UHI) is a metropolitan area which is significantly warmer than its surrounding regions. The temperature difference usually is larger at

night than during the day and larger in winter than in summer. The main reason of the urban heat island is modification of the land surface by urban development. As vegetation is replaced by asphalt and concrete for roads, buildings, and other

artificial structures, urban heat islands form. These “artificial ground” absorb the sun's heat, causing surface temperatures and overall ambient temperatures to rise. Due to urban heat island phenomena, the energy cost increases and environment for human beings becomes discomfort.

Recently, technologies have been explored to alleviate urban heat island phenomena by replacing the existing asphalt pavements with “environmentally-friendly pavements”. Porous pavement and interlocking blocks may be helpful to reduce pavement temperature by inducing evaporation. Water-retentive or water absorbing pavements are even more effective. These pavement materials hold water and let it evaporated during sunny days.

In this study, we aimed at the development of new permeable and water-absorbing pavement blocks. Bottom ash (BA) from coal burning power plants was used to explore the possibility waste recycling for producing environmentally-friendly material. Optimum conditions for high mechanical strength and water absorption were investigated for production of the pavement blocks from bottom ash. In addition, removal efficiencies of pollutants in road runoff by the pavement blocks were compared under various conditions.

2. EXPERIMENTAL

2.1 Materials

Sample of BA was obtained from the coal burning power station located Boryung, South Korea. Chemical composition of BA is shown on Table I. As evident from Table 1, the silicon dioxide content in BA is low(45%~50%) and the sum of $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ reaches 75%. It means that BA belongs to ASTM C 618 type C ash. The specific gravity of bottom ash is 2.3. BA was screened on sieve with size of 850 μm , 2mm, 4.75mm before being used in the experiments. The cement was used

commercial portland cement. Specific gravity of cement was 3.15g/cm^3 . Initial and final settling times were 2.5 and 4.3h, respectively. Its blaine surface area was $3,480\text{cm}^2/\text{g}$. The lime was added to the binder for initiating the pozzolanic reaction and for improving long time strength gain. And to water-retention and removal of pollution materials, peat was used as water-retentive material and pollution material solution. Peat is a polar, highly porous and specific surface area (McLellan and Rock, 1988), material that could have significant applications as an adsorbent for removal of heavy metals from aqueous solutions (Christ, R.H et al., 1966, Ringqvist and Oborn, 2002). Peat mainly contains lignin and cellulose. Functional groups in lignin that include alcohols, aldehydes, ketones, acids, phenolic hydroxides, and ethers allow it to bind with various metal ions. To test on the homogenous situation, particles with 350 μm ~2mm were used to test by screen on sieve.

2.2 Experimental procedure

Composition of test specimens

The mixture proportions and some properties of mixtures are given in Table II.

It can be seen from Table II, two different mixtures were prepared according to earlier studies in which proportions of BA, cement and lime were determined. These mixtures are; normal mixture with different aggregates, normal mixture with material for water-retentive and water-purification. The specimens were molded from mixture of various proportions of BA aggregate size mixed thoroughly with equal amount of cement and lime.

Preparation of test specimens

Several series of test specimens (19×9×5 cm, 4MPa pressure) were made, differing in the composition. Mixing of raw materials(coal ash, cement, calcium oxide) was prepared in Hobart mixer. Test specimens were cast by concrete block

Table I: Materials composition (% by weight)

Material	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	TiO ₂	P ₂ O ₅	LOI
BA	46.1	18.7	10.2	18.8	1.80	0.82	0.97	0.79	0.58	0.62

Table II: Mix proportion

unit : g

Specimen	Bottom ash			W	C	Ca	AD
	5mm~	2mm ~5mm	850 μ m ~2mm				
B111C2A1	4168	3648	3496	1357	2262	226	0
B122C2 A1	2605	4560	4370	1384	2307	231	0
B112C2 A1	3126	2736	5244	1333	2221	222	0
B121C2 A1	3126	5471	2622	1346	2244	224	0
B121C2A1D2	3126	5471	2622	1346	2244	224	180
B121C2A1D3	3126	5471	2622	1346	2244	224	225
B121C2A1D4	3126	5471	2622	1346	2244	224	360
B121C2A2D2	3,126	5,471	2,622	1,488	2,307	554	150.00
B121C3A1D2	3,126	5,471	2,622	1,603	3,366	337	150.00
B121C3A3D2	3,126	5,471	2,622	1,603	3,366	1,121	150.00

machine with pressure 4MPa. The specimens were kept in the molds for 24h at 20°C room temperature. After demolding, specimens were kept at 20±1 °C in a curing cabinet until testing dates. Relative humidity of the curing cabinet was 50±10%.

**Figure 1:** Concrete Block Machine

Test of the specimens

The series of tests are carried out according to ASTM C 67-03a to determine the water absorption, the compressive strength values of the samples.

Three cube specimens, 19×9×5 cm, were used for compressive strength tests. The compressive strength was determined by taking the average of test results of three specimens. The strengths of samples after curing for 7 and 28 days were measured using a compression testing machine.

$$\text{Compressive strength} = P / A$$

Where, P : Maximum load (MPa)

A : Area (cm²)

For the determination of water absorption, cubes were taken from the curing tank at the desired curing age and placed in an oven at

Table III: Results of test

Specimen	Compressive strength (MPa)		Absorption (%)
	7 days	28days	
B111C2A1	7.7	9.0	8.73
B122C2 A1	4.4	6.2	10.34
B112C2 A1	2.9	4.3	11.00
B121C2 A1	11.0	14.4	7.62
B121C2A1D2	10.2	12.3	17.31
B121C2A1D3	9.4	10.6	17.52
B121C2A1D4	6.7	8.1	18.73
B121C2A2D2	7.2	9.0	13.82
B121C3A1D2	12.5	15.1	16.70
B121C3A3D2	3.8	5.7	13.01

100°C until a constant mass was achieved. This took about 3 days. The cubes were left to cool in an air-tight container. The dry mass of specimens was determined before they were immersed in water for half an hour. The absorption was then calculated as the ratio of water mass absorbed to that of dry mass of sample and expressed as a percentage.

To estimate the treatment efficiency of polluted rainwater by the pavement blocks, road runoff was collected in real roadway during rainfall events. The collected rainwater was then applied into the pavement blocks and the samples were collected before and after passing through the blocks. Turbidity and heavy metal concentrations in the samples were analyzed to calculate the removal of these pollutants by the blocks.

3. RESULTS

Compressive strength

As shown in Table III, compressive strengths decreased with decreasing the size of aggregate in the blocks. This is attributed to an increase in specific surface area, which leading to a decrease in the content of cement. With increasing the content of cement, compressive strength increased

**Figure 2:** Compressive strength test

but porosity decreased. Thus, it is likely that the relative amount of cement should be less than 30 %.

As the content of lime exceeded 20%, compressive strength increased due to expansion. The content of peat moss should not be over 30% because it reduces the coherence force among aggregates, leading to a decrease in mechanical strength.

Accordingly, the optimum conditions for block formation were given by:

- i) Composition of bottom ash:
Aggregates over 5 mm – 25 %, aggregates between 2 mm to 5 mm – 50 %, aggregates between 0.85 mm to 2 mm – 25 %
- ii) Relative amount of cement – 20~30 %

- iii) Relative amount of lime – 10 %
- iv) Peat moss – 20 %

In Table III, B121C2A1D2 and B121C3A1D2 were produced under conditions similar to the optimum ones. The compressive strengths after 7 days for these blocks were 10.2 MPa and 12.5 MPa, respectively. The compressive strengths after 28 days were slightly higher. They were 12.3 MPa and 15.1 MPa, respectively, which were enough for use as C-type block 2nd grade in the Korean Standard.

Absorption

Figure 3 shows the water absorption for various blocks. The water absorption increased as the block contained bottom ash aggregates of smaller diameters. This is probably because the small aggregates have high porosity. Considering the fact that blocks containing small-sized aggregates exhibited weak strength, it is likely that the size of aggregate is a key parameter to determining mechanical strength and water absorption efficiency.

As peat moss was added, the water absorption increased from 7~11 % (without peat moss) to 16 % (with peat moss). Moreover, the mechanical strength was also high and the structure was stable. This result implies that peat moss acts as a water absorbing material as well as binding material.

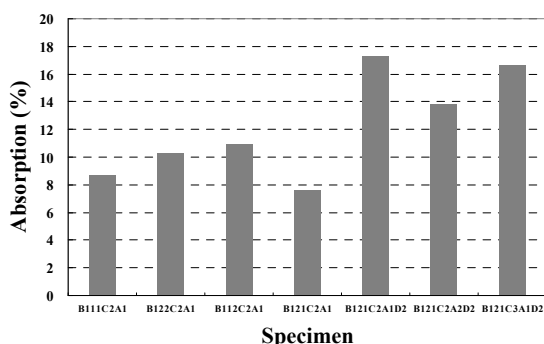


Figure 3: Comparison of water-absorption efficiency for various bottom ash blocks

Removal of pollution material

Using the contaminated rainwater from real roadway, the removal of pollutants by the ECO blocks were examined. The area of pavement samples were 50×50 cm. Specially designed water spays were used to simulate natural rainfall. Silicon adhesive was added between the blocks to prevent bypass of rainwater. Thus, all the rainwater was passed through the blocks and collected at the bottom of the equipment for further chemical analysis.



Figure 4: Water quality purification test of bottom ash block

Two blocks including bottom ash blocks BB and BBPM (bottom ash block with peat moss) were compared in terms of turbidity removal. Turbidity of feed water (contaminated rainwater) was 290 NTU, while turbidity of water from BB was 71.8 NTU, indicating the turbidity removal was 75%. Addition of peat moss in the block helps to improve turbidity removal. The turbidity of water from BBPM was only 6.1 NTU, corresponding to 98% removal of turbidity.

Table IV compares the concentrations of heavy metals and ions in the effluent of blocks after 7 days of production. BB shows slightly higher concentrations of As, Cr, and C because the test was performed before complete consolidation. Nevertheless, effluent from BBPM showed lower concentrations of heavy metals and ions than FW and BB effluent. Especially, the

concentrations of Hg, Mn, and Pb were almost zero in BBPM effluent, indicating the blocks containing peat moss have potential to control heavy metals in contaminated rainwater.

Table IV: Comparison of water quality for BBW and BBPMW

Sample	(unit : mg/ℓ)		
	FW	BBW	BBPMW
As	0.012	0.028	0.022
Cd	0.006	0.003	0.002
Cr	0.081	0.260	0.085
Cu	0.111	0.288	0.024
Fe	16.120	3.404	0.188
Hg	0.012	0.001	0.000
Mn	0.688	0.147	0.005
Pb	0.125	0.031	0.000

4. CONCLUSION

In this study, ECO blocks made of bottom ash and peat moss were developed and examined as a new technique to control urban heat island problem. The following conclusions were drawn:

- (1) The compressive strength, water absorption, and pollution control ability were dependent on the amount of size of bottom ash aggregate and peat moss content.
- (2) The blocks made of bottom ash aggregates (large:medium:small): cement:lime:peat moss of 58(25:50:25):30:10:2 showed reasonably high strength of 15.1 MPa, with high water absorption of about 17%.
- (3) Turbidity and heavy metals in rainwater were successfully removed by adding peat moss to the blocks.

The performed tests presented in this paper constitute only a first step research to apply to be used peat moss as block

materials and the further tests are possibly needed prior to use the new bricks as construction materials.

The further tests will be required such as the pore size distribution and durability test by variables of bottom ash block changing the replacement percentage of peat moss, lime etc. This further information on the new blocks would allow proposing this composite as new building material.

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