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Engineering Properties of Permeable Polymer Concrete Using Bottom Ash and Recycled Coarse Aggregate

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Abstract

Permeable polymer concretes can be applied to roads, sidewalks, river embankment, drain pipes, conduits, retaining walls, yards, parking lots, plazas, interlocking blocks, etc. This study was to explore a possibility of using bottom ash as filler and recycled coarse aggregate of industrial by-products for permeable polymer concrete. The tests carried out at 20±1℃ and 60±2% relative humidity. At 7 days of curing, unit weight, void ratio, compressive and flexural strength and coefficient of permeability ranged between 1,652～1,828 kgf/m^3, 15～29%, 18.2～24.5 MPa, 6.4～8.4 MPa, and 6.8×10^{-2}～1.7×10^{-1} cm/s, respectively. It was concluded that the bottom ash and recycled coarse aggregate can be used in the permeable polymer concrete.

Keywords : Permeable polymer concrete, Bottom ash, Recycled coarse aggregate, Unit weight, Void ratio, Strengths, Coefficient of permeability

I. Introduction

Demand for concrete material supply has been widening with the rapid growth of the construction industry. Supply of natural materials from river beds and mountains are not sufficient. Environmental problems associated with the material collection from river beds by dredging and from mountains by excavation have caused strong protests from environmentalists. With the growth of construction industry, the supply of materials in the construction industry was been pressing problems to solve in the near future. Application of industrial by-products of concrete has widely increased, and recent studies have found to the excellent compatibility between those industrial by-products and polymers.[7),9),10)]

The use of polymer concrete as an alternative to cement concrete products has been increasing because of its super physical and mechanical properties, chemical resistance, durability, strong adhesion and rapid curing.[2)]

This study initiated to find a way to reuse

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industrial by-products as precious resource. A way to reuse the industrial by-products is to use them as construction material. The objectives of this study are to find a way to reuse bottom ash as filler and recycled coarse aggregate as aggregate.

Ⅱ. Materials

1. Unsaturated Polyster Resin

An ortho phthalate-type unsaturated polyster resin with an accelerator was used in this study, and its general properties are shown in Table 1.

Table 1 General properties of unsaturated polyester resin

Density (g/cm², 20℃)	Viscosity (20℃, poise)	Styrene content (%)	Acid value
1.12	3.5	37.2	26.5

2. Hardener

Hardener was used for normal hardening and its general properties are shown in Table 2.

Table 2 General properties of hardener

Component	Density (g/cm³, 20℃)	Active oxygen (%)
MEXPO 55% DMP 45%	1.13	10.0

3. Aggregates

Aggregates used were recycled coarse aggregate and natural fine aggregate. The aggregates were dried at 100±5℃ for one day before use.[4)] Physical properties of the aggregates are shown in Table 3.

Table 3 Physical properties of aggregates

Item	Size (mm)	Unit weight (kgf/m³)	Density (g/cm², 20℃)	Absorption rate (%)	Fineness modulus
Recycled coarse aggregate	5~10	1,562	2.62	1.87	6.49
Natural fine aggregate	0.6~5	1,500	2.59	1.12	2.82

4. Filler

Bottom ash was used in this study because it is relatively cheap and easy to buy. Filler was dried at 100±5 ℃ for one day before use.[4)] Physical properties and chemical composition of the filler are shown in Table 4 and Table 5.

Table 4 Physical properties of bottom ash

Density (g/cm³, 20℃)	Specific surface (cm²/g)	Unit weight (kgf/m³)	Grain size (mm)	Color
2.42	2,300	1,200	<0.15	Gray

Table 5 Chemical composition of bottom ash

(Unit: %)

SiO_2	Al_2O_3	K_2O	Fe_2O_3	Na_2O	MgO	CaO	TiO_2	lg.loss
46.1	18.7	0.82	10.2	0.97	1.80	18.8	0.09	0.62

5. Mix Proportions of Permeable Polymer Concrete

After many preliminary tests, six mix proportions were tried to determine an optimum mix proportions of permeable polymer concretes using bottom ash and recycled coarse aggregate contents of unsaturated polyester resin based binder with the hardening system, filler and aggregates were fixed as seen in Table 6.

Table 6 Mix proportions of permeable polymer concrete (Unit: wt, %)

Mix type	Binder		Aggregate		Filler	Total
	Unsaturated polyester resin	Hardener	Natural fine	Recyled coarse	Bottom ash	
BPPC0	6.94	0.07	16.16	76.83	0.00	100
BPPC1	7.14	0.07	15.38	75.41	2.00	100
BPPC2	7.43	0.07	13.89	74.61	4.00	100
BPPC3	7.71	0.08	12.99	73.22	6.00	100
BPPC4	8.00	0.08	11.79	72.13	8.00	100
BPPC5	8.34	0.08	11.13	70.40	10.00	100

6. Manufacture and Curing of Specimens

Specimens were manufactured according to the Korean Standard Testing Methods, KS F 2419 (Specimen preparation methods for strength measure of polyester resin concrete). Permeable polymer concretes were mixed by using a high performance concrete mixer. Two types of specimen, i.e., cylindrical and block specimens, were made depending on test. Specimens were molded by putting permeable polymer concrete into a cylindrical and block molds, and the molds were put on a table vibrator and compacted sufficiently by vibration for three minutes. All the specimens were demolded after curing at a room temperature of 20±1 ℃ for three hours, and cured again at 20±1 ℃ and 60±2% relative humidity for up to 7 days.

Ⅲ. Methodology

1. Unit Weight

Unit weight of permeable polymer concrete was evaluated from the following equation.

$$UW = \frac{W_c}{V_c}$$

where, UW is unit weight (kgf/m^3), Wc is weight and Vc is volume of permeable polymer concrete.

2. Void Ratio

For the void ratio test, a specimen of ∅100×200 mm was made of the porous polymer concrete. It was inserted in the plastic mold and filled with water. The void ratio was calculated by measuring the volume of water.

3. Compressive strength

Compressive strength test of specimen was carried out according to the KS F 2481 (Compressive strength test method for polyester resin concrete). Strength test was carried out at the 7 days of curing, and the size of cylindrical was ∅100×200 mm.

4. Flexural Strength

Flexural strength test of specimen was carried out according to the KS F 2482 (Flexural strength test method for polymer resin concrete). Strength test was carried out at the 7 days of curing, and the size of beam specimens was 60×60×240 mm.

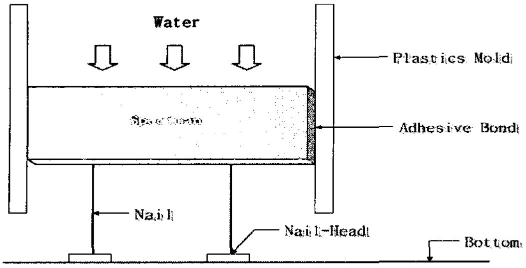

Fig. 1 Permeability coefficient testing apparatus

5. Coefficient of Permeability

The water level was about 5 cm, the amount of permeated water was 10 ℓ, and the experiments were repeatedly performed 5 times. Coefficient of permeability was measured by volume of permeated water(cm/s). The size of beam specimens was 240×240×40 mm. The permeability coefficient testing apparatus for permeable polymer concretes used in this study is shown in Fig. 1.

Ⅳ. Results and Discussion

1. Unit Weight

Table 7 shows the results of unit weight tests on permeable polymer concrete. Unit weight of permeable polymer concrete ranged from 1,652 ~1,828 kgf/m^3 and it was largely dependent upon the mix proportions, and it was decreased from 20 to 28% than that of normal cement concrete (2,300 kgf/m^3). Unit weight of permeable polymer concrete was mainly affected by coefficient of permeability.[8)]

Unit weight is increased with increasing the content of bottom ash. The highest unit weight was shown by 100% filled bottom ash and the lowest unit weight was shown by 0% filled bottom ash as filler for permeable polymer concrete.

Table 7 Test results of permeable polymer concrete

Mix type	Unit weight (kgf/m^3)	Void ratio (%)	Strength (MPa)		Coefficient of permeability (cm/s)
			Compressive	Flexural	
BPPC0	1,652	29	18.2	6.4	1.7×10^{-1}
BPPC1	1,666	28	18.8	6.6	1.4×10^{-1}
BPPC2	1,687	26	19.7	7.4	1.1×10^{-1}
BPPC3	1,711	23	21.3	7.7	1.0×10^{-1}
BPPC4	1,738	19	23.9	8.1	8.3×10^{-2}
BPPC5	1,828	15	24.5	8.4	6.8×10^{-2}

2. Void Ratio

Void ratios of permeable polymer concrete are shown in Table 7 and Fig. 2. Void ratio ranged 15~29%, which are approximately satisfied for planting void ratio 20~30%.[3)]

Void ratio is decreased with increasing the content of bottom ash and are decreased 3.4~48.3% according to the content used of bottom ash.

The highest void ratio was shown by 0% filled

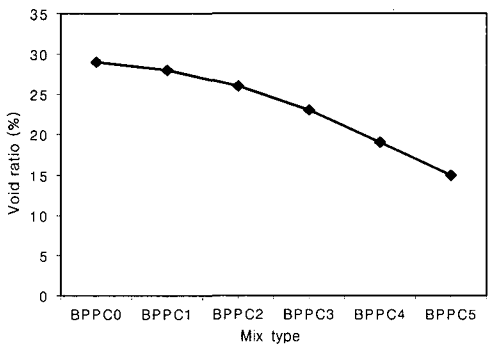

Fig. 2 Comparison of void ratio by mix type

bottom ash and the lowest void ratio was shown by 100% filled bottom ash as filler for permeable polymer concrete.

3. Compressive Strength

Strength development of permeable polymer concrete was assumed to be related to the content of bottom ash as filler. Thus, strength tests were performed with respect to the different content of filler. Table 7 and Fig. 3 shows the results of compressive strength tests. The highest compressive strength was achieved by 100% filled bottom ash as filler, and the choice of filler is very important.[1)]

Compressive strength ranged 18.2~24.5 MPa and is increased with increasing the content of bottom ash and are increased with 3.2~34.6% according to the content used of bottom ash.

It is thought that such result is due to increasing the coating thickness of the aggregates by binder content increased because the mix proportion of the binder was the most important factor for the strength of the permeable polymer concrete.[6)]

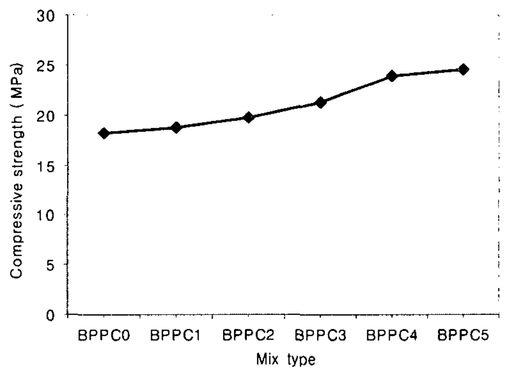

Fig. 3 Comparison of compressive strength by mix type

Compressive strength was greater than the standard compressive strength 18 MPa for permeable concrete pavement. It is expected that the utilization of recycled coarse aggregate and bottom ash for the manufacture of permeable polymer concrete for permeable pavement will be useful.

4. Flexural Strength

Flexural strength was used for the standard design strength for pavement plates, concrete pipe and concrete piles subject to flexural stress such as roads and runways.

The requirements on the flexural strength are presented for the concrete plates and concrete blocks for sidewalk and driveways. Flexural strength of permeable polymer concrete are shown in Table 7.

The highest flexural strength was achieved by 100% filled bottom ash as filler.

Flexural strength ranged 6.4~8.4 MPa and is increased with increasing the content of bottom ash and are increased with 3.1~31.2% according to the content used of bottom ash as filler. Flexural strength was interrelated with the compressive strength and coefficient of permeability.[9)]

It is expected that the utilization of recycled coarse aggregate and bottom ash for permeable polymer concrete pavement and permeable block will be useful.

Accordingly, the application of permeable polymer concrete structures are subject to flexure stress can be used.

5. Coefficient of Permeability

Table 7 and Fig. 4 show the coefficient of permeability of permeable polymer concrete. Measured coefficient of permeability of permeable polymer concrete was in the range of $6.8 \times 10^{-2} \sim 1.7 \times 10^{-1}$ cm/s and it was largely dependent upon the mix proportions. In all mix proportions, it was greater than the standard permeability coefficient 1×10^{-2} cm/s for permeable concrete pavement.[5)]

The highest coefficient of permeability was shown by 0% filled bottom ash and the lowest coefficient of permeability was shown by 100% filled bottom ash as filler for permeable polymer concrete.

It proved that the permeability of permeable polymer concrete was superior. Accordingly, these permeable polymer concretes can be used for structures which needs appropriate strength and coefficient of permeability.[7)]

In the permeable concrete pavement, the greater permeability coefficient is advantageous. The permeating capacity of the drainage layer must be considered for the construction of permeable pavement, and the mutual permeating capacity of permeable blocks and drainage layer must be reflected in the mix proportions.

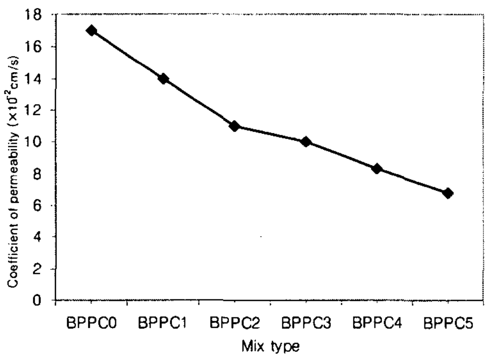

Fig. 4 Comparison of coefficient of permeability by mix type.

V. Conclusions

This study was performed to evaluate the engineering properties of permeable polymer concrete using bottom ash, recycled coarse aggregate, unsaturated polyester resin and hardener. The following conclusions were drawn from the test results;

1. Unit weight of permeable polymer concrete ranged from 1,652 to 1,828 kgf/m^3 and it was largely dependent upon the mix proportions. It was mainly affected by coefficient of permeability.

2. Void ratio was in the range of 15~29%, which are satisfied for planting void ratio 20~30% and are decreased 3.4~48.3% according to the content used of bottom ash.

3. Compressive strength of permeable polymer concrete ranged between 18.2~24.5 MPa. The highest compressive strength was achieved by 100% filled bottom ash and is increased with increasing the content of bottom ash as filler. Compressive strength was greater than the standard compressive strength 18 MPa for permeable concrete pavement. It is expected that the utilization of recycled coarse aggregate and bottom ash for the manufacture of permeable polymer concrete for permeable pavement will be useful.

4. Flexural strength ranged between 6.4~8.4 MPa and is increased with increasing the content of bottom ash. Flexural strength was interrelated with the compressive strength and coefficient of permeability. It is expected that the utilization of

recycled coarse aggregate and bottom ash for permeable polymer concrete pavement and permeable block will be useful.

5. Coefficient of permeability of permeable polymer concrete was in the range of 6.8×10^{-2}~ 1.7×10^{-1} cm/s and it was greater than the standard permeability coefficient 1×10^{-2} cm/s for permeable concrete pavement. These permeable polymer concretes can be used for structures which needs appropriate strength and coefficient of permeability.

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