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Physical and Mechanical Properties of Permeable Polymer Concrete Utilizing Industrial By-Products

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Abstract □ Permeable polymer concrete can be applied to roads, sidewalks, river embankment, drain pipes, conduits, retaining walls, yards, parking lots, plazas, interlocking blocks, etc. This study is to explore a possibility of utilizing industrial by-products, a blast furnace slag and a fly ash, as fillers for permeable polymer concrete. Different mixing proportions are tried to find an optimum mixing proportion of permeable polymer concrete. The tests are carried out at 20±1°C and 60±2% relative humidity. At 7 days of curing, compressive, flexural and splitting tensile strengths and water permeability ranged between 239~285kgf/cm^2, 107~133kgf/cm^2, 37~46kgf/cm^2 and 4.612~5.913 ℓ/cm^2/h, respectively. It is concluded that the blast furnace slag and fly ash can be used in permeable polymer concrete.

Keywords □ filler, permeability, strength, modulus of elasticity, strain, permeable polymer concrete

I. Introduction

Demand for concrete material supply has been widening with the rapid growth of 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. And with the growth of construction industry, the supply of materials in construction industry have been pressing question to solve in near future. Application of blast furnace slag and fly ash as an additive or filler of concrete has widely increased and recent studies have found to the excellent compatibility between those industrial by-products and polymers.[6,8]

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

This study initiated to find a way to reuse an industrial by-products as a precious resource. A way to reuse the industrial by-products is to use it as a construction material. The objectives of this study are (1) to find a way to reuse industrial by-products as filler for permeable polymer concrete that has properties of high strengths, (2) to test the permeable polymer concrete that uses an industrial by-products as filler with respect to engineering properties, and (3) to provide the test data for factory production of permeable polymer concrete products.

II. Materials

1. Unsaturated Polyester Resin

An ortho-type unsaturated polyester resin is used in this study and its general properties are shown in Table 1.

Table 1. General properties of unsaturated polyester resin

Specific gravity at 20℃	Viscosity at 20℃ (poise)	Styrene content (%)	Acid value
1.12	3.5	37.2	26.5

2. Hardener

Hardener used in this study is for normal hardening and its general properties are shown in Table 2.

Table 2. General properties of hardener

Component	Specific gravity at 20℃	Active oxygen (%)
MEKPO 55% DMP 45%	1.13	10.0

3. Aggregates

A natural coarse aggregate which was collected from a river bed was used and it was dried at 100±5℃ for one day before use.[4)] A blast furnace slag was used as a fine aggregate. Physical properties of aggregates are shown in Table 3.

Table 3. Physical properties of aggregates

Classification	Size (mm)	Specific gravity (20℃)	Absorption (%)	F.M	Unit weight (kgf/m^3)
Coarse aggregate	4.76~10	2.63	2.15	6.00	1,550
Fine aggregate	0.595~4.75	1.76	1.20	3.11	978

4. Filler

Commonly used fillers include powder of fly ash, heavy calcium carbonate, alumina, blast furnace slag powder, silica, cement, stone

Table 4. Chemical composition and physical properties of fillers

Item		Blast furnace slag powder	Fly ash
Chemical composition (Unit : wt. %)	SiO_2	27.16	55.89
	Al_2O_3	9.34	25.27
	K_2O	-	0.61
	Fe_2O_3	3.40	5.45
	Na_2O	-	0.39
	MgO	7.73	1.43
	CaO	48.30	6.38
	SO_3	3.89	0.08
	Ig. loss	0.18	4.50
Bulk density (kgf/m^3)		2.90	1.29
Specific surface (Blain)(cm^2/gf)		4,665	3,260
Grain size (mm)		<0.150	<0.150
Color		White	Gray

dust and so on. Among these, blast furnace slag powder and fly ash were used in this study because it is relatively cheap and easy to buy. Fillers were dried at 100±5℃ for one day before use.[4] Chemical composition and physical properties of fillers are shown in Table 4.

5. Mixing proportions

After many preliminary tests, 5 mixing proportions were experimentally evaluated to determine an optimum mixing proportion of permeable polymer concrete. The contents of unsaturated polyester resin, hardener, fillers and aggregates were fixed as in Table 5.

Table 5. Mixing proportions of permeable polymer concrete

(Unit : kgf/m^3)

Mix Type	Binder		Aggregate		Filler		Total
	Unsaturated polyester resin	Hardener	Fine	Coarse	Blast furnace slag powder	Fly ash	
SF1	137.61	1.39	299	1,242	187	-	1,867
SF2	140.58	1.42	303	1,260	142	47	1,894
SF3	145.53	1.47	313	1,301	98	98	1,957
SF4	142.56	1.44	307	1,278	48	144	1,921
SF5	138.60	1.40	301	1,250	-	188	1,879

6. Manufacture and Curing of Specimens

Specimens were prepared according to the Korean Standard Testing Methods, KS F 2419 (Specimen preparation methods for strength measure of polyester resin concrete). Permeable polymer concrete 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 formed by putting permeable polymer concrete into a cylindrical and block mold, the mold was put on a table vibrator and compacted sufficiently by vibration. All the specimens were demolded after cured at 20±1℃ room temperature for three hours, and cured again at 20±1℃ for up to 7 days.

Ⅲ. Methodology

1. Water Permeability

The water level is about 5cm, the amount of permeated water is 10ℓ, and the experiments are repeatedly performed 5 times.

Water permeability is measured by volumn of permeated water(ℓ/cm^2/h). The size of block specimen is 20cm×20cm×7cm. The permeability testing apparatus for permeable polymer concrete used in this study is shown in Fig.1.

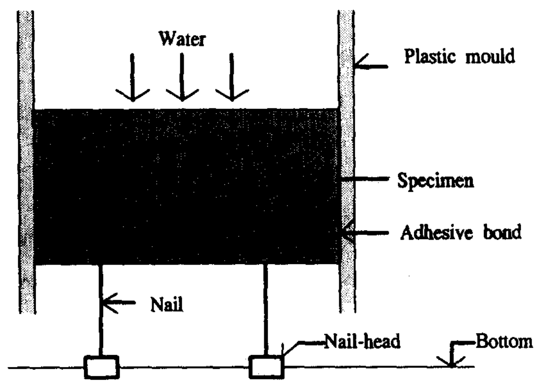

Fig. 1. Schematic drawing of permeability testing apparatus

2. Strengths

Compressive, flexural and splitting tensile strength tests were carried out according to KS F 2481 (Compressive strength test method for polyester resin concrete), KS F 2482 (Flexural strength test method for polyester resin concrete), and KS F 2480 (Splitting tensile strength test method for polyester resin concrete), respectively.

The size of cylindrical specimen was ϕ 10cm × 20cm and block specimen was 6cm × 6cm × 24cm.

3. Static Modulus of Elasticity, Poisson's Ratio and Strain

Tests for static modulus of elasticity and Poisson's ratio were performed by using the strain gauge method which is specified in KS F 2438 (Testing method for static modulus of elasticity and Poisson's ratio in compression of cylindrical concrete specimens).

Loads were applied up to 40% of the failure load. The size of cylindrical specimen was ϕ 15cm × 30cm.

4. Dynamic Modulus of Elasticity

Dynamic modulus of elasticity test was carried out according to BS 1881 part 203 (Recommendation for the measurement of dynamic modulus of elasticity).[7] The test was conducted by excitation in the longitudinal mode of vibration. The size of cylindrical specimen was ϕ15cm × 30cm.

Ⅳ. Results and Discussion

1. Water Permeability

Table 6 shows the results of water permeability test on permeable polymer concrete. Measured water permeability of permeable polymer concrete ranged from 4.612 to 5.913 ℓ/cm²/h which were 150 times as high as in the world maximum rainfall 300mm, and it is largely dependent upon the mixing proportion. The highest water permeability was shown by 100% filled blast furnace slag powder (SF1) as filler. It proved that the permeability of permeable polymer concrete was superior. Accordingly, these permeable polymer concrete can be used as the members and structures which needs appropriate strength and water permeability.

Table 6. Results of water permeability tests of permeable polymer concrete

Mix Type	Water permeability (ℓ/cm²/h)
SF1	5.913
SF2	5.166
SF3	4.612
SF4	4.884
SF5	5.526

2. Strengths

Strength developments of permeable polymer concrete were assumed to be related to the content of blast furnace slag powder and fly ash as fillers. And thus, strength tests were performed with respect to the different content of fillers. Table 7 shows the results of compressive, flexural and splitting tensile strengths. The highest strength was achieved by 50% filled blast furnace slag powder and fly ash as filler, and the choice of filler is very importantl). It was increased compressive strength by 36%, flexural strength by 217% and splitting tensile strength by 119% than that of normal cement concrete, respectively.

Table 7. Strengths of permeable polymer concrete

Mix Type	Strength (kgf/cm^2)		
	Compressive	Flexural	Splitting tensile
SF1	239	107	37
SF2	244	118	42
SF3	285	133	46
SF4	260	127	43
SF5	240	115	39

Table 8 shows the strength ratio of permeable polymer concrete with different mixing proportion. The strength ratio is one of the important properties of permeable polymer concrete. The ratio of flexural strength to compressive strength of permeable polymer con=-crete ranged between 0.448 and 0.488, which was 2.4times higher than that of normal cement concrete. Also, the compressive strength of permeable polymer concrete was higher, and the flexural strength was much higher than that of normal cement concrete, respectively. It can be explained that the polymer has a particular property and thus, the toughness of polymer concrete is higher than that of normal cement concrete.

Accordingly, the application of permeable polymer concrete in the structures for bending would be very useful.

Table 8. Strength ratio of permeable polymer concrete

Mix Type	f_t/f_c	f_b/f_c	f_t/f_b
SF1	0.155	0.448	0.346
SF2	0.172	0.484	0.356
SF3	0.161	0.467	0.346
SF4	0.165	0.488	0.338
SF5	0.163	0.479	0.339

3. Static Modulus of Elasticity, Poisson's Ratio and Strain

The test results of the static modulus of elasticity, Poisson's ratio and strain of permeable polymer concrete are shown in Table 9. The static modulus of elasticity ranged $100\times10^3 \sim 130\times10^3 kgf/cm^2$, which was approximately 43~51% of that of normal cement concrete. The Poisson's number and strain of permeable polymer concrete were smaller and larger than that of normal cement concrete, respectively. Also, static modulus of elasticity increased with the increase of strength.[3)]

Table 9. Static modulus of elasticity, Poisson's ratio and strain of permeable polymer concrete

Mix Type	Static modulus of elasticity ($\times10^3 kgf/cm^2$)	Poisson's		Strain ($\times10^{-3}$)	
		Ratio	Number	Longitudinal	Horizontal
SF1	100	0.233	4.293	0.425	0.099
SF2	117	0.231	4.319	0.488	0.113
SF3	130	0.276	3.621	0.525	0.145
SF4	121	0.252	3.976	0.497	0.125
SF5	109	0.235	4.257	0.481	0.113

4. Dynamic Modulus of Elasticity

Dynamic modulus of elasticity of permeable polymer concrete is shown in Table 10. Dynamic modulus of elasticity ranged $102\times10^3 \sim 130\times10^3 kgf/cm^2$, which was approximately smaller than that of normal cement concrete. Dynamic modulus of elasticity is interrelated with the compressive, flexural and splitting tensile strengths and water permeability.[5)] This technique offers potentially useful nondestructive test methods to identify the physical condition of concrete.

Table 10. Dynamic modulus of elasticity of permeable polymer concrete

Mix Type	Dynamic modulus of elasticity ($\times 10^3$kgf/cm^2)
SF1	102
SF2	122
SF3	130
SF4	123
SF5	111

V. Conclusions

This study was performed to evaluate the physical and mechanical properties of permeable polymer concrete utilizing industrial by-products. An unsaturated polyester resin was used as binder, and blast furnace slag powder and fly ash were used as fillers. The following conclusions are drawn.

1. Water permeability ranged 4.612~5.913 ℓ/cm^2/h and was largely dependent upon the mixing proportion. It was inversely dependent upon the magnitude of the concrete strengths. These permeable polymer concretes can be used as a member of structures which need appropriate strength and water permeability.

2. Compressive, flexural and splitting tensile strengths ranged between 239~285kgf/cm^2, 107~133kgf/cm^2 and 37~46kgf/cm^2, respectively. The highest strength was achieved by 50% filled blast furnace slag powder and fly ash as filler, and the choice of filler is very important. It was increased compressive strength by 36%, flexural strength by 217% and splitting tensile strength by 119% than that of normal cement concrete, respectively. The increase of the flexural strength of permeable polymer concrete was higher than the increase of the compressive strength, compared to that of normal cement concrete, and those concrete to the structures which is subject to flexure stress can be used.

3. ft/fc and fb/fc of permeable polymer concrete were 0.155~0.172 and 0.448~0.488, respectively, and are larger than those strength ratios of normal cement concrete. ft/fb of permeable polymer concrete was 0.338~0.356, and was smaller than those strength ratio of normal cement concrete. The ratio of flexural strength to compressive strength of permeable polymer concrete was 2.4 times higher than that of normal cement concrete. It suggests that the permeable polymer concrete have a great advantage for the design and production of concrete structures.

4. Static modulus of elasticity and Poisson's ratio ranged between 100×10^3~130×10^3kgf/cm^2 and 0.231~0.276, respectively. Static modulus of elasticity and Poisson's ratio of permeable polymer concrete were smaller and larger than that of normal cement concrete, respectively. Also, permeable polymer concrete showed higher strain than that of normal cement concrete.

5. Dynamic modulus of elasticity ranged 102×10^3~130×10^3kgf/cm^2, which was approximately smaller than that of normal cement concrete. The dynamic modulus of elasticity were increased approximately 2~4% than that of static modulus of elasticity.

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