JOURNAL OF THE KOREAN SOCIETY OF AGRICULTURAL ENGINEERS DEC. 2005, pp. 25-33

JOURNAL OF THE KOREAN SOCIETY OF AGRICULTURAL ENGINEERS, Vol. 47, No. 7

# Characteristics of Environment-Friendly Porous Polymer Concrete for Permeable Pavement

**Kim, Young Ik* · Sung, Chan Yong****

**Abstract**

This study was performed to develop environment-friendly porous polymer concrete utilizing recycled aggregates [RPPC] for permeable pavement of uniform quality with high permeability and flexural strength as well as excellent freezing and thawing resistance. The void ratios of RPPC are in the range of 15~24%, showing the tendency that it is reduced to a great extent as the mixing ratio of the binder increases. The compressive and flexural strength of RPPC are in the range of 19~26 MPa and 6.2~7.4 MPa, respectively. Also, it shows a tendency to increase as the mixing ratio of the binder and filler increases. The permeability coefficients of RPPC are in the range of $6.3\times10^{-1}\sim1.5\times10^{-2}$cm/s. The flexural loads of RPPC are in the range of 18~32 KN. The weight reduction ratios obtained from the test for freezing and thawing resistance are in the range of 1.1~2.4% after 300 cycles of repeated freezing and thawing of the specimen for all mixes. The relative compressive strengths of RPPC after 300 cycles of freezing and thawing against the compressive strength before freezing and thawing test are in the range of 89~96%.

*Keywords : Porous polymer concrete, Permeable pavement, Recycled aggregate, Permeability coefficient, Strength, Freezing and thawing*

## I. Introduction

Concrete has contributed to the development of economy and culture by being used for social infrastructures such as roads, railroads, harbors, waterways and wastewater systems. However, as environmental problems have become prominent social issues, concrete has been recognized negatively from the aspects of natural environmental protection as a material causing environmental destruction to forests and nature and preventing inhabitation of animals and plants.

Therefore, many studies are actively performed concerning not only the uses of industrial by-products and solid wastes as admixture for concrete but also environment-friendly concrete in order to develop special concrete such as

* Institute of Agricultural Science, Chungnam National University

** Professor, Division of Bio-Resources Engineering, College of Agriculture and Life Sciences, Chungnam National University

** Corresponding author. Tel.: +82-42-821-5798
Fax: +82-42-821-8877
E-mail address: cysung@cnu.ac.kr

living things protective concrete and environmental load reduction concrete.[1),2)] Particularly, concrete has been made porous and used for sound absorption, water permeation, vegetation and water purification recently according to void characteristics. Many studies are aggressively carried out on the utilization of incineration ash, sewage sludge, fly ash, blast furnace slag and waste concrete to reduce the environmental load. On the other hand, due to surface pavement using impermeable paving material, rainwater directly flows into the rivers during heavy rain, causing floods and ground water depletion.[4)] Therefore, studies are actively performed to develop permeable concrete and porous concrete with draining ability, which can replace impermeable cement concrete and asphalt. However, in the case of permeable cement concrete pavement and asphalt pavement, partial settlement and destruction occur because of concrete cracks and aggregate fall-off by repeated freezing and thawing in winter due to low flexural and tensile strength.

Therefore, this study was performed to develop environment-friendly porous polymer concrete utilizing recycled aggregates for permeable pavement of uniform quality with high permeability and flexural strength as well as excellent freezing and thawing resistance and to provide fundamental data for the manufacture of permeable pre-cast blocks. Also, it was performed to examine the physical and mechanical characteristics of porous polymer concrete according to the mixing ratio of the binder and filler.

## Ⅱ. Experimental Program

### 1. Materials

As a binder for manufacturing porous polymer concrete, ortho type unsaturated polyester resin was used and DMP solution containing methyl ethyl ketone peroxide by 55% was used as an initiator. Table 1 shows the general properties of unsaturated polyester resin. As the coarse aggregates, crushed stones and the first class recycled aggregate produced by "I" manufacturing company in Gyeonggi-do were used and their physical properties are presented in Table 2. In addition, blast furnace slag granulated by cooling melted slag from the blast furnace rapidly was utilized as the filler to increase the concrete

**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 |

**Table 2 Physical properties of coarse aggregate**

| Type | Size (mm) | Bulk density (kg/m³) | Specific gravity (20℃) | Absorption ratio (%) | Fineness modulus |
|---|---|---|---|---|---|
| Crushed | 5-10 | 1,581 | 2.64 | 1.25 | 6.72 |
| Recycled | 5-10 | 1,562 | 2.62 | 1.87 | 6.49 |

**Table 3 Physical properties of filler**

| Type | Specific gravity (20℃) | Specific surface (㎠/g) | Unit weight (kgf/㎥) | Grain size (mm) | Color |
|---|---|---|---|---|---|
| Blast furnace slag | 2.92 | 4,401 | 1,077 | 〈 0.15 | White |

strength, and Table 3 displays its physical properties.[3)]

## 2. Mix Proportions and Manufacture

The most significant factor on the strength, permeability, continuous void ratio and freezing and thawing resistance of the porous polymer concrete for permeable pavement is the amount of the binder used. If it is too much, voids are filled with excessive amounts of filler after aggregates are coated with polymer, and impermeable layers are formed at the bottom making the concrete impervious. Therefore, it is very important to apply the proper amount of binder. In addition, since the strength and void ratio have a contradictory relation; it is crucial to choose an optimum mix proportion that satisfies these two conditions. The mix proportion of the binder, filler and coarse aggregate was determined to satisfy the requirement for the permeability coefficient, $1\times10^{-2}$ ㎝/s for general permeable cement concrete pavement as well as the flexural load 11 KN required for the A-type sidewalk pavement concrete plate and void ratio of 15~25 for permeability. In addition, various binders (7, 8 and 9 wt.%) and fillers (19, 21 and 23 wt.%) were used to examine the characteristics of void ratio, strength, permeability coefficient, etc. and mix designs are shown in Table 4.[6)] To formulate the porous polymer concrete for permeable pavement, the binder was fed to the filler and aggregates and mixed using a high speed mixer for approximately 3 minutes so that the aggregates could be coated sufficiently by the binder. Then the coated aggregates were placed in a mold and compacted by a vibrator. After 3 hours, the concrete was removed from the mold and cured until the curing age of 7 days.

## 3. Test Method

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

**Table 4 Mix designs of porous polymer concrete**

(Unit: $kgf/m^3$)

| Mix Type | Binder | | Coarse aggregate | | Filler |
|---|---|---|---|---|---|
| | Unsaturated polyester resin | Hardener | Crushed | Recycled | Blast furnace slag powder |
| Control | 180 | 1.80 | 1,600 | - | 480 |
| RPPC1 | 165 | 1.65 | - | 1,700 | 440 |
| RPPC2 | 180 | 1.80 | - | 1,600 | 480 |
| RPPC3 | 195 | 1.95 | - | 1,500 | 520 |

filled with water. Then the void ratio was calculated by measuring the volume of water. For the compressive strength test, a specimen of ∅ 100×200 mm was prepared. The test was performed at the curing age of 7 days by KS F 2481 (Method for Testing Compressive Strength of Polyester Resin Concrete). The flexural strength test was performed with specimen of 100×100×400 mm by KS F 2482 (Method for Testing Flexural Strength of Polyester Resin Concrete). The permeability test was performed by tightly contacting a specimen of 300×300×60 mm to the permeability test device and filling with water as shown in Fig. 1. The permeability coefficient was obtained by measuring the time during which 6 ℓ water permeated through the specimen 5 times and averaging the measured values. For the flexural load test, a specimen of 300×300×60 mm was made as shown in Photo 1. The test was performed in accordance with the method specified by the KS F 4001 (Method for Testing Flexural Load for Sidewalk Concrete Plate). For the freezing and thawing resistance test, a specimen of 76×76×412 mm was created. The rapid freezing and thawing test was performed at the curing age of 7 days in accordance with the method specified by KS F 2456 (Method for Testing Rapid Freezing and Thawing Resistance of Concrete). At this time the temperature of the specimen applied for freezing and thawing was −18℃ and 4℃, respectively. One cycle of freezing and thawing took 4 hours. During the test period, the weight reduction ratio was measured at the interval of 50 cycles. The test was completed at 300 cycles of freezing and thawing, and then the compressive strength was measured.[8)]

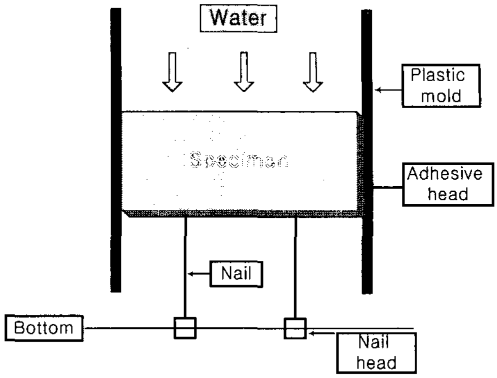


**Fig. 1 Test apparatus permeability coefficient**

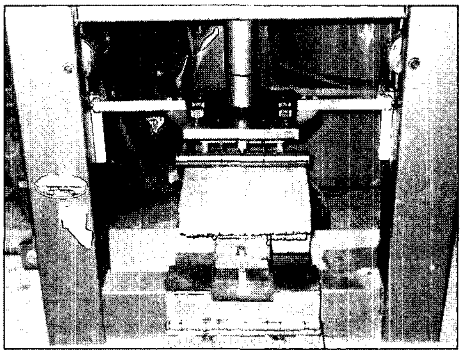

**Photo 1 Test apparatus for flexural load**

## Ⅲ. Results and Discussion

### 1. Void ratio

The void ratio of the Control type porous polymer concrete using crushed stones as aggregate is 18% and the void ratios of the porous polymer concrete utilized recycled aggregate are in the range of 15~24%. Also, it shows the tendency that it is reduced to a great extent as the mixing ratio of the binder increases as shown in Table 5. It is thought that such result was obtained because the mixing ratio of the filler was increased to suppress the clogging of voids

**Table 5 Test results of porous polymer concrete for permeability pavement**

| Mix type | Air void (%) | Strength (MPa) | | Coefficient of permeability (cm/s) | Flexural load (KN) | After 300 cycles of freezing and thawing | |
|---|---|---|---|---|---|---|---|
| | | Compressive | Flexural | | | Weight reduction ratio (%) | Compressive strength (MPa) |
| Control | 18 | 23 | 7.2 | $1.5\times10^{-1}$ | 28 | 1.8 | 22 |
| RPPC1 | 24 | 19 | 6.2 | $6.3\times10^{-1}$ | 18 | 2.4 | 17 |
| RPPC2 | 20 | 22 | 7.0 | $2.4\times10^{-1}$ | 24 | 1.9 | 20 |
| RPPC3 | 15 | 26 | 7.4 | $1.5\times10^{-2}$ | 32 | 1.1 | 25 |

due to the increase in the fluidity of the binder, which resulted in the coating thickness increase of aggregates through the mixing of binder and filler. In addition, for the porous polymer concrete with the binder of same mixing ratio in weight percent, the void ratio is reduced a little less in the case of the Control type compared to the RPPC2 type. This means that the cross-linking between aggregates when crushed stones were mixed was more superior to when recycled aggregates were mixed. It is thought that such result is obtained because the plate-shaped crushed stones have greater cross-linking effect than the round-shaped recycled aggregates. However, target void ratio was obtained for all mixes utilizing recycled aggregates. Therefore, it is thought that the use of recycled aggregates for porous polymer concrete has no significant problem. Moreover, manufacturing porous polymer concrete for permeable pavement requires the binder and filler to be increased in order to secure high strength. Since this may cause the problem of securing void ratio that meets the required condition for permeability, despite the great mixing ratio of the binder, the mix design that allows the formation of sufficient voids is necessary for securing permeability.

## 2. Compressive strength

The compressive strength of the Control type porous polymer concrete using crushed stones is 23 MPa and the compressive strengths of the porous polymer concrete utilizing recycled aggregates are in the range of 19~26 MPa as shown in Table 5. It is thought that such result is due to increasing the coating thickness of the aggregates by binder increased because the mixing ratio of the binder was the most important factor for the strength of the porous polymer concrete.[7),10)] In addition, for the porous polymer concrete with the binder of identical mixing ratio in weight percent, the compressive strength increases a little in the case of the Control type compared to the RPPC2 type. But, the compressive strength became greater than the standard compressive strength of 18 MPa for permeable pavement. It is expected that the utilization of recycled aggregates for the manufacture of porous polymer concrete for permeable pavement will be useful environmentally in the aspect of replacing crushed stones and reusing aggregates. Moreover, the void clogging phenomenon must not occur due to high fluidity of the binder to secure strength when manufacturing the porous polymer concrete for permeable pavement. Accordingly, it is important to increase the viscosity of the polymer matrix by increasing the filler as well as the binder. Therefore, for the porous polymer concrete, the binder must be increased followed by the increase of filler to meet the required conditions for strength and void ratio.

## 3. Flexural strength

The flexural strength is used for the standard design strength for pavement plates, concrete pipes, concrete piles, etc. subject to flexural stress such as roads or runways. Currently, the requirements on the flexural strength are presented for the concrete plates for sidewalks and concrete blocks for sidewalk sand driveways. The flexural strength for the Control type porous polymer concrete is 7.2 MPa and the flexural strengths of the porous polymer concrete utilizing recycled aggregates are in the range of 6.2~7.4 MPa as shown in Table 5. Like the case of the compressive strength, the flexural strength shows a tendency to increase as the mixing ratio of the binder and filler increases. In the case of porous cement concrete for permeable pavement, the compressive strength can be increased by increasing the binder. However, since the flexural strength is low relatively, it is difficult to use the porous cement concrete where high flexural load is applied.[5),10)] In contrast, it is expected that the porous polymer concrete can be used for concrete plates for permeable pavement or permeable blocks since it has greater flexural strength.

## 4. Permeability coefficient

The permeability coefficient of the porous polymer concrete for permeable pavement is the most important factor. It is required to have a value that allows rain water to permeate through the concrete. The permeability coefficient of the Control type porous polymer concrete is $1.5\times10^{-1}$ cm/s. The permeability coefficients of the porous polymer concrete using recycled aggregates are in the range of $6.3\times10^{-1}\sim1.5\times10^{-2}$ cm/s as shown in Table 5. Like the case of the void ratio, the permeability coefficient shows a tendency to decrease as the mixing ratio of binder and filler increases. However, for all mixes, it is greater than the standard permeability coefficient of $1.0\times10^{-2}$ cm/s for permeable pavement.[7)] On the other hand, in the case of permeable pavement, the greater permeability coefficient is advantageous. However, the permeating capacity of the drainage layer must be considered for the construction of permeable pavement and the mutual permeating capacity of permeating blocks and drainage layer must be reflected in the design.

## 5. Flexural load

The porous cement concrete has a disadvantage that its flexural load decreases to a great extent despite its high compressive strength due to the low binding force of the binder. Conversely, the flexural load of the Control type porous polymer concrete is 28 KN. The flexural loads of the porous polymer concrete using recycled aggregates are in the range of 18~32 KN as shown in Table 5. Like the cases of compressive strength and flexural strength, flexural load shows a tendency to increase as the mixing ratio of the binder and filler increases. In addition, for all mixes of porous concrete using recycled aggregates, it is high above the standard flexural load of 11 KN applied to sidewalk pavement concrete plates. It is thought that such high flexural load is obtained due to not only the excellent adhesion characteristics of the aggregate and polymer matrix but also to the binding force increase between aggregates since the unsaturated polyester resin used as the binder has greater adhesive force than the cement.

## 6. Freezing and thawing resistance

### 6.1 Weight reduction ratio

Amount of binder and void ratio have immense influence on the freezing and thawing resistance of the porous concrete. Particularly, it is known that the freezing and thawing resistance of the porous concrete decreases significantly since it contains a great amount of moisture in the voids due to its characteristics. The weight reduction ratios obtained from the test for freezing and thawing resistance are in the range of 1.1~2.4% after 300 cycles of repeated freezing and thawing of the specimen for all mixes using crushed stones and recycled aggregates, and the weight reduction ratio is very low regardless of the mixing ratio of binder and filler as shown in Table 5. Generally, in the case of porous cement concrete, if the freezing and thawing is repeated continuously, the fall-off of aggregates occurs conspicuously due to the low adhesion characteristics of the binder and the reduction of adhesive force between aggregates. Whereas in the case of porous polymer concrete, the durability reduction phenomenon such as aggregate fall-off did not occur after 300 cycles of freezing and thawing. It is thought that this reason is due to increasing the adhesion of aggregates through the use of unsaturated polyester resin with high adhesion characteristics.

### 6.2 Compressive strength

The compressive strengths for all mixes using crushed stones and recycled aggregates are in the range of 17~25 MPa after 300 cycles of freezing and thawing. The compressive strength was very high regardless of the mixing ratio of the binder and filler as shown in Table 5. In the case of the porous cement concrete, the aggregate fall-off was too much due to the low adhesion characteristics of the binder and the compressive strength also decreased to a great extent due to the decrease in the adhesive force. On the other hand, in the case of the porous polymer concrete, the compressive strength was far greater than the standard compressive strength for permeable pavement after 300 cycles of freezing and thawing due to excellent adhesion characteristics. Moreover, the relative compressive strengths of the porous polymer concrete after 300 cycles of freezing and thawing against the compressive strength before freezing and thawing test were in the range of 89~96%, showing almost no decrease in the compressive strength according to the repeated freezing and thawing. Therefore, it is expected that the porous polymer concrete will have high freezing and thawing resistance in winter if it is utilized for permeable pavement.

### 7. Pre-cast porous polymer block

In the production of the porous polymer concrete block in the factory, it is important that the specimen maintain constant viscosity with the mold being removed immediately after placing the porous polymer concrete in the mold so that the block can maintain its shape, disallowing the concrete to flow out by self-weight. Generally, the polymer concrete shows the tendency that its workability decreases rapidly along with time. Accordingly, it is desirous that in order to continuously perform the following processes smoothly, the block be fabricated by rapidly performing the placement and mold removal before the porous polymer concrete in the same batch, which has not hardened yet. Therefore, the mixing amount of hardening acceleration agent that had influence on the hardening time of the porous polymer concrete was selected by considering the quantity of produced blocks and required continuous working time per single batch operation.[9] The site mix was performed based on the indoor mix test result. Photos 2 and 3 show the shape of pre-cast permeability products and permeability appearance of porous polymer block.

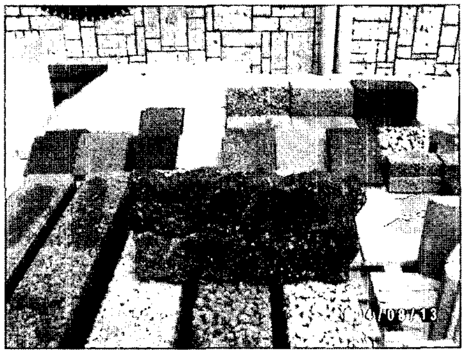

**Photo 2 Pre-cast permeability products**

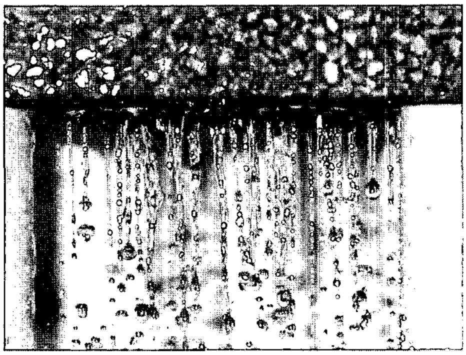

**Photo 3 Permeability appearance of porous polymer block**

## Ⅳ. Conclusions

This study was performed to develop environment-friendly porous polymer concrete utilizing recycled aggregates [RPPC] for permeable pavement of uniform quality with high permeability and flexural strength as well as excellent freezing and thawing resistance.

The following conclusions are drawn :

1. The void ratio of the Control type porous polymer concrete using crushed stones as aggregate is 18% and the void ratios of the porous polymer concrete using recycled aggregate are in the range of 15~24%.

2. The compressive strength of Control is 23 MPa and RPPC are in the range of 19~26 MPa, and the compressive strength increases as the mixing ratio of the binder and filler was increases.

3. The flexural strengths of RPPC are in the range of 6.2~7.4 MPa. It is expected that the

porous polymer concrete can be used for permeable pavement or permeable blocks since it has greater flexural strength.

4. The permeability coefficients of RPPC are in the range of $6.2\times10^{-1}\sim1.5\times10^{-2}$ cm/s and it shows a tendency to decrease as the mixing ratio of binder and filler increases. For all mixes, it was greater than the standard permeability coefficient of $1.0\times10^{-2}$ cm/s for permeable pavement.

5. The flexural loads of RPPC are in the range of 18~32 KN. It is high above the standard flexural load of 11 KN applied to sidewalk pavement concrete plates for all mixes of porous concrete using recycled aggregates.

6. The relative compressive strengths of the porous polymer concrete after 300 cycles of freezing and thawing against the compressive strength before freezing and thawing test are in the range of 89~96%. Therefore, it is expected that the porous polymer concrete has high freezing and thawing resistance in winter if it is utilized for permeable pavement.

## References

1. Choi, L. and J. C. Kim. 1998. ECO-Concrete, *Magazine of the Korea Concrete Institute* 10(6): 11-21. (in Korean)
2. Japan Concrete Institute. 1995. ECO-Concrete Research Committee Report, *Japan Concrete Institute*, Tokyo: 5-30 (in Japanese)
3. Khatri, R. P. and V. Sirivivatnanon, 1995, Effect of different supplementary cementitious materials on mechanical properties of high performance concrete, *Cement and Concrete Research* 25(1): 209-220.
4. Lee, S. H. and E. K. Kim. 2000. A review of environment conscious concrete, *Magazine of the Korea Concrete Institute* 12(5): 17-22. (in Korean)
5. Neville, A. M., 1981, Properties of concrete, *Pitman publishing limited*, London, U. K: 605-635.
6. Paturoyer, V. V., 1986, Recommendations on polymer concrete mix design, *NIZHB*, Moscow : 18.
7. Sung, C. Y., 1995, Mechanical characteristics of permeable polymer concrete, *Proceedings of the '95 Japan and Korea Joint Seminar*, Tottori University, Japan: 32-35. (in Korean)
8. Sung, C. Y. and Y. I. Kim., 1999. Experimental study on freezing and thawing resistance of rice straw ash concrete. *Journal of the Korean Society of Agricultural Engineer* 41(3): 66-72. (in Korean)
9. Vipulanandan, C., N. Dharmarajan and E. Ching., 1988, Mechanical behavior of polymer concrete system, *Materials and Structures* 21(124): 268-277.
10. Yeon, K. S., et al., 1993, Effects of fillers on mixing and mechanical properties of polymer concrete, *Journal of the Korean Society of Agricultural Engineers*, 35(2): 81-91. (in Korean)