Structural Test of Precast Polymer Concrete

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ABSTRACT: This study was performed to check the feasibility of concrete polymer manhole through a development test of high strength polymer concrete and prepare fundamental data for design to solve the problems of the existing cement concrete manhole. The lower absorption capacity (0.39%) of polymer concrete will be more advantageous in installing manhole in an area with subsurface water. Also long working-life (63 minutes) will be enough to establish manholes. Conclusively, the high strength polymer concrete that is the most important issue in development of polymer concrete manhole could be made. © 2009 Wiley Periodicals, Inc. J Appl Polym Sci 114: 1370–1376, 2009

Key words: monomers; strength; structure; polymer concrete manhole

INTRODUCTION

General

Recently various kinds of polymer-based materials are getting largely used in construction field. Because polymer has not only impact resistance, formability, and light self-weight that the other materials do not have but also competitive power enough for economy.[1–6]

In addition, various social problems are caused by traffic congestion and worse environment of residence due to increase of construction works. Therefore constructions are positively getting manufactured in plants and polymer concrete is focused as a material for such constructions.

Polymer concrete is relatively expensive but it has high impact resistance, so that it is widely used in the products for underground facilities including communication, electric power, gas and water service, etc.[7–11] In addition, reasonable priced and practical polyester resin polymer is used to manufacture the manholes by mixing the aggregates such as gravels, sands, and various thermosetting resins that are binders. The existing cement concrete is cheap and simple to be used and has some merits: nonflammability and durability, etc., so that it has been used as a construction material since long time ago. However, it has also a number of demerits: it is easily cracked because it has weak tensile and flexural strength, and it is also weak against chemicals especially acids. That is why polymer concrete is getting widely used as a new material that can supplement such demerits of cement concrete in construction industry field.[12,13]

This study is, therefore, aimed to check the feasibility of concrete polymer manhole through a development test of high strength polymer concrete and prepare fundamental data for design to solve the problems of the existing cement concrete manhole.

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MATERIALS AND METHODS

Nature of polymer concrete materials

Resins and hardeners

Table I shows the physical natures of the resins and hardeners used in this study.

Fillers

Fillers are added into resins mainly to reduce the cost per unit volume and improve the durability, stability, and strength of polymer concrete. Fillers are consist of calcium carbonate, alumina, silica stone, powder silicone carbide, iron oxide and cement, etc among which calcium carbonate is widely used because it costs low and is easy in buying. Calcium carbonate is finely powered by crushing limestone and it is classified to hard and soft

TABLE I
Physical Nature of Resins and Hardeners

Materials	Appearance	Structural formula	Specific gravity (20°C)	Role
Unsaturated polyester	Corn-colored liquid	—(O—CH_2—CH_2—COO—CH =CH—COO—CH_2—CH_2—O—)—	1.12	Base
Styrene	Colorless liquid	C_6H_5—CH=CH_2	0.9	Connector, viscosity adjuster
MEKPO (45% DMP contained)	Colorless liquid	HO-(-O-C(CH_3)(C_2H_5)-O)n-OH	1.12	Hardener

type, the hard one is suitable for polymer concrete. In this study, two kinds of hard type calcium carbonate particles specified in the Table II below were mixed in proportion of HC-1(40%) and HC-2(60%).

Aggregate

Polymer concrete also needs gravel and sand as needed for cement concrete. Artificial aggregates are also used for some specific cases because they have a specific merit although they are expensive. Natural aggregates are selected under the condition as cement concrete is selected. However, they should be dried so that their moisture content is 0.3% or lower because their strength decreases as it increases.[14–16]

In general, when water is absorbed to hydrophilic aggregates, water membrane is formed between the binder layer around the aggregates and the surface of such aggregate then it weakens the adhesive force between the binder and the aggregates. In this study, therefore, the aggregates were fully dried so that their moisture content is 0.1% or lower. Tables III and IV show the physical properties of aggregates used in this study.

Shrinkage reducing agent

Shrinkage of polyester polymer concrete gets to be faster as the amount of accelerator and catalyst increases, and the value is known as 3.5/1000–5.5/1000. The large amount of shrinkage of polyester is disadvantageous for manufacturing a big member. To reduce the value, it is important to decide the concrete mixture proportioning that can make the volume of resin as small as possible. However, a shrinkage reducing agent should be used for essential solution. The compressive strength may, however, be reduced if large amount of the shrinkage reducing agent is used, and it is recommended to use the minimum amount of shrinkage reducing agent. Generally shrinkage reducing agent is made by dissolving granule type polystyrene in styrene monomer, however it takes so long. Table V shows the ingredients and nature of the shrinkage reducing agent used in this study.

Releasing agent

It is necessary to use a releasing agent to demold easily after hardening of the polymer concrete. An interior releasing agent mixed with polymer concrete in advance and an exterior releasing agent applied onto a mold surface. It also includes synthetic polymers such as silicone and semisolid wax that are melted at low temperature according to its ingredients. In this study, semitransparent semisolid paraffin wax (C_nH_{2n+2}) was used as an exterior releasing agent.

Test specimens

Table VI shows the specification of a polymer photomanhole.

EXPERIMENTAL

Test of physical and mechanical properties of polymer concrete

This test is aimed to examine physical and mechanical properties of polymer concrete focused on some

TABLE II
General Nature of Hard Type Calcium Carbonate

Type	Specific gravity	Absorption capacity (%)	PH	Average particle size (μm)	Remaining of # 325 sieve (%)
HC-1	0.75	0.3	8.8	13	0.03
HC-2	0.75	0.3	8.8	35.3	33

TABLE III
Physical Nature of Fine Aggregate

Specific gravity	Absorption capacity (%)	Unit weight (kg/m^3)	Passing rate of # 200 sieve (%)	Fineness modulus
2.60	0.75	1500	0.68	2.73

TABLE IV
Physical Nature of Coarse Aggregate

Max. size (mm)	Specific gravity	Absorption capacity (%)	Unit weight (kg/m^3)	Abrasion rate (%)
20	2.62	0.653	1791	26.3

of the properties needed to develop a manhole. In detail, the physical properties were specific gravity, absorption capacity, working-life and workability, etc and the mechanical properties were strength, modulus of elasticity, and Poisson's ratio, etc.

Mixture proportioning

In general, the strength of polymer concrete increases as the amount of resin increases, however, the resin is separated, shrunken, and bent when resin is used 12% or higher. Therefore the optimized resin volume should be calculated considering the workability and formation of stir. In most cases, large volume of filler and sand is used to reduce the surplus resin in mixing polymer concrete. However, use of excessive volume of filler makes the viscosity to be large and the workability becomes worse and compressive and flexural strength also become lower. High fineness modulus tends to reduce the strength, and it is recommended to use fine particle for the strength. In addition, the mixture proportioning of aggregate should be made to have the minimum volume of void and the content of fine sand is known to have the biggest effect on the strength. However, polymer concrete should be made after repeated tests to get desired workability because it changes according to volume of resin, fineness modulus of aggregate, and volume of filler, etc. Table VII shows the mixture proportioning used in this study.

Test specimens

Specimens were made in accordance with the method specified in test method of specimen for strength test of polyester resin concrete. Mixing was done by a concrete mixer. Considering the test period, specimens for compressive and flexural strength were cured at high temperature and the others were cured at the room temperature, which means curing at 23°C continuously for 7 days. High temperature curing means hardening at the room temperature 23°C for 24 h and then hardening in a dry oven adjusted at 75°C for 16 h.

TABLE V
Ingredients and Nature of Shrinkage Reducing Agent

Viscosity (25°C, ps)	Polystyrene (%)	Styrene monomer (%)	Appearance
35	36	64	Transparent

TABLE VI
Specification of Polymer Photo-manhole

Specimens	Inner size (cm) Length × Width × Height	Thickness (cm) Top × Bottom × Side
Polymer photo-manhole type II	190× 120 × 150	10× 8 × 5
Polymer photo-manhole type III	240× 150 × 180	13× 12 × 6
Polymer photo-manhole type IV	320× 150 × 180	13× 12 × 7

Test methods

Specific gravity and absorption capacity. The specific gravity and absorption capacity of polymer concrete were tested in accordance with ASTM C 127-01.[17] The size of specimens were 5 × 5 × 5 cm^3.

Working-life. Working-life was measured by using both Injection Method and Touching Method (JIS A 1186[18]) among many methods specified to measure the casting time of polyester resin concrete. Working-Life has been measured because liquid resin catalyst (MEKPO) was added. It was tested at 20°C and 60% humidity.

Workability. The workability of polymer concrete is tested usually through Slump Test and Flow Test in accordance with ASTM C 109-02.[19] In this study, the workability was measured through the flow test because the maximum size of the aggregate was not bigger than 20 mm and the binder was highly viscous. The flow test of cement concrete is done through falling 15 times for 15 s, however, it of polymer concrete was done through falling at the same speed for 10 min in this study.

Strength. The strength tests were done in accordance with ASTM C 39-03[20] and C 580-02.[21] The specimen size of cylinder was φ7.5×15 cm and it of beam was 6 × 6 × 24 cm^3. Figures 1 and 2 show the compressive and flexural strength test, relatively.

Modulus of elasticity and Poisson's ratio. The modulus of elasticity and Poisson's ratio were measured by the wire strain gauge method in accordance with ASTM C 469-02.[22] The specimen size of cylinder was φ7.5 × 15 cm^2, and 70 mm strain gauge was used

TABLE VII
Mixture Proportioning of Polymer Concrete

Polyester (%)	MEKPO (phr)	Shrinkage reducing agent (phr)	Calcium carbonate (%)	Aggregate (%)
10.5	1	25	10.5	89

Figure 1 Compressive strength test.

for measurement of longitudinal strain and 30 mm one for lateral strain.

Modulus of elasticity is gained by the formula as follows:

$$E = (\sigma_2 - \sigma_1)/(\varepsilon_1 - 0.000050) \quad (1)$$

E: Modulus of elasticity ($\times$ 10 MPa)

ε_1: Longitudinal strain of the specimen at 40% of maximal loading

σ_1: Compressive stress of the specimen ($\times$ 10 MPa) at the longitudinal strain is 50×10^{-6}

σ_2: Compressive stress of the specimen ($\times$ 10 MPa) at 40% of maximal loading

Poisson's ratio is gained by the formula as follows:

$$\upsilon = (\varepsilon_{t1} - \varepsilon_{t2})/(\varepsilon_1 - 0.000050) \quad (2)$$

ε_1: Longitudinal strain of the specimen at 40% of maximal loading

υ: Poisson's Ratio

ε_{t1}: Lateral strain of the center of the specimen at the stress σ_2

ε_{t2}: Lateral strain of the center of the specimen at the stress σ_1

Figure 2 Flexural strength test.

TABLE VIII
Specific Gravity and Absorption Capacity Test Result

Specific gravity		Absorption capacity (%)	
Test results	Mean	Test results	Mean
2.31, 2.29, 2.30	2.30	0.32, 0.44, 0.40	0.39

RESULTS AND DISCUSSION

Test result and review

Specific gravity and absorption capacity

Table VIII shows the specific gravity and absorption capacity test result of the polymer concrete. This result indicated that the specific gravity of polymer concrete is 2.30, that is, almost similar to that of cement concrete. In addition, the absorption capacity of polymer concrete is 0.39%, which is not only much smaller than that of cement concrete, 4–6%, but also even smaller than that of typical concrete aggregate, 0.5–4.0%, shows the superiority of polymer concrete in water-proof property. It is considered that the manhole made by polymer concrete is shown no leakage unlike cement concrete.

Working-life

When polymer concrete products are made by room temperature hardening method, it is one of the most important issues to set its working-life properly, that is, working-life should be proper for the appearance, size, production process, etc. Working-life is influenced by temperature and the amount of the accelerator (CoOc) and catalyst (MEKPO). Table IX shows the working-life tested in this study.

Workability

Polymer concrete is quite different from the ordinary cement concrete in terms of construction work, therefore it may not be convenient to be applied to normal construction. Because it should be handled by different methods depending on its types and many of engineers have not been skilled for it. Therefore the manufacturers' guide books should be investigated before handling the resin. The casting temperature is adequate about room temperature. For thermosetting resin its viscosity becomes higher at lower temperature, and its viscosity becomes

TABLE IX
Working-Life Test Result

	Test results	Mean
Working-life (min)	61, 63, 65	63

TABLE X
Flow Test Result

	Test results	Mean
Flow (%)	29.3, 27.2, 28.1	28.2

lower at higher temperature then it is subject to segregate. In general, such resin set forth above has high viscosity, which, however, largely changes as temperature changes. Such changeable viscosity has a great influence on the volume of resin and workability. Under the condition that the same volume of styrene is added, therefore, lower resin viscosity makes the resin attached to the aggregate surface thinner and the resin flow higher, so that the workability becomes to improve. In this study, flow test was done based on the change of resin volume. Table X shows the flow value measured at 10.5% resin volume.

Strength test

Strength of polymer concrete is deeply related to the volume of binder, proportion of fine and coarse aggregate, curing condition and volume of shrinkage reducing agent, etc. Especially, it is known to become higher with more volume of binder. However, excessive volume of binder makes such defects as separation of resin and large amount of shrinkage. It is, therefore, necessary to optimize the volume of binder considering the strength when polymer concrete is mixed.

In this study, compressive and flexural strength were tested using the specimens manufactured by 10.5 wt % resin and 25 phr shrinkage reducing agent as mentioned above. The test results are shown in Tables XI and XII and Figures 3–7, which indicate that the compressive strength is 127 MPa and flexural strength is 22 MPa in average. The coefficient of variation was 7.2% for compressive strength and 6.3% for flexural strength. The values are satisfied with the rule of ACI Committee 214[23] that 10% or

TABLE XI
7-Day Compressive Strength Test Result

Specimens	Test results (MPa)	Mean (MPa)
Polymer photo-manhole Type IV (heated)	136, 135, 136	136
Polymer photo-manhole Type IV (air dry)	127, 132, 130	130
Polymer photo-manhole Type III (heated)	133, 133, 134	133
Polymer photo-manhole Type III (air dry)	115, 115, 116	115
Polymer photo-manhole Type II (air dry)	118, 110, 114	114

TABLE XII
7-Day Flexural Strength Test Result

Specimens	Test results (MPa)	Mean (MPa)
Polymer photo-manhole Type IV (heated)	23.6, 22.9, 20.5	22.3
Polymer photo-manhole Type IV (air dry)	20.4, 22.2. 20.0	20.9
Polymer photo-manhole Type III (heated)	22.1, 23.6, 24.8	23.5
Polymer photo-manhole Type III (air dry)	21.3, 21.1, 20.0	20.9
Polymer photo-manhole Type II (air dry)	21.0, 20.7, 17.9	19.8

less coefficient of variation for strength was good for cement concrete. This result is thought to indicate that polymer concrete has a narrow variation band of strength apparition condition unlike cement concrete.

The strength ratio was calculated by using the average value of the compressive and flexural strength specified in Tables XI and XII. The ratio of compressive and flexural strength was 5.7. Generally the ratio for a typical concrete with 60 MPa compressive strength is about 8.8 and it for granite rock with 150 MPa compressive strength is about 13.6. Therefore, it was investigated the ratio of the polymer concrete was quite low because polyester resin used as binder with high toughness. This result indicates that polymer concrete is advantageous as a material for manholes.

Modulus of elasticity and Poisson's ratio

The relation between compressive strength and Poisson's ratio for polymer concrete is shown in Figures 8 and 9, which also indicate similar tendency to the stress–strain of cement concrete. As shown in Tables XIII and XIV, therefore, the modulus of

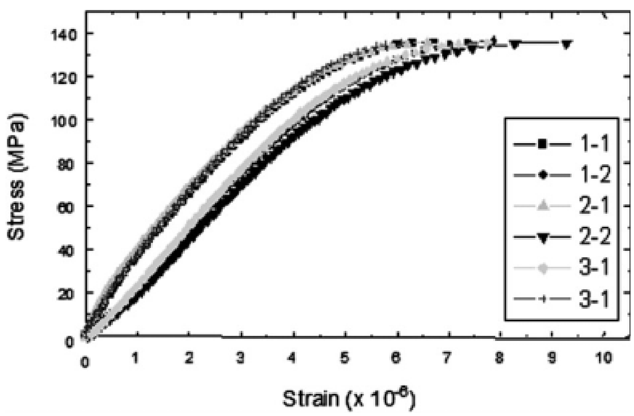

Figure 3 σ-ε Curve [specimen 4 (heated)].

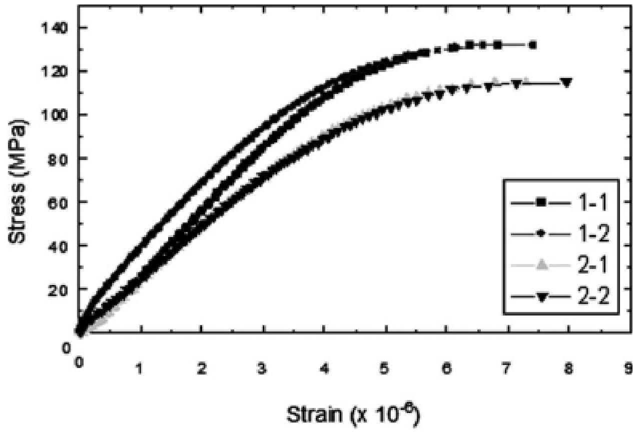

Figure 4 σ-ε Curve [specimen 4 (air dry)].

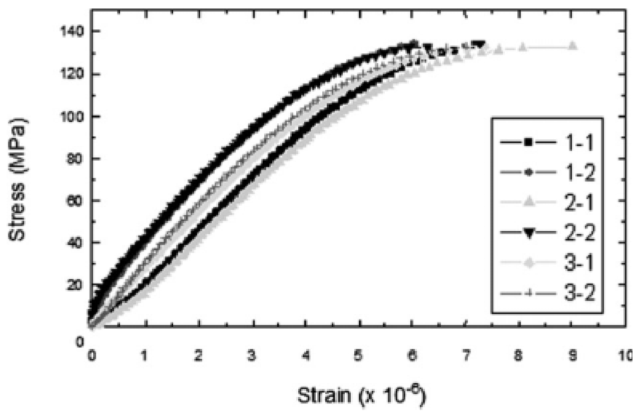

Figure 5 σ-ε Curve [specimen 3 (heated)].

elasticity was 2.8×10^4 MPa and Poisson's ratio was 0.21 in average. Considering the cement concrete with 70–90 MPa compressive strength, the modulus of elasticity is 4.5×10^4 MPa and Poisson's ratio of typical cement concrete is 0.08–0.16, this result indicates that the modulus of elasticity is very small and

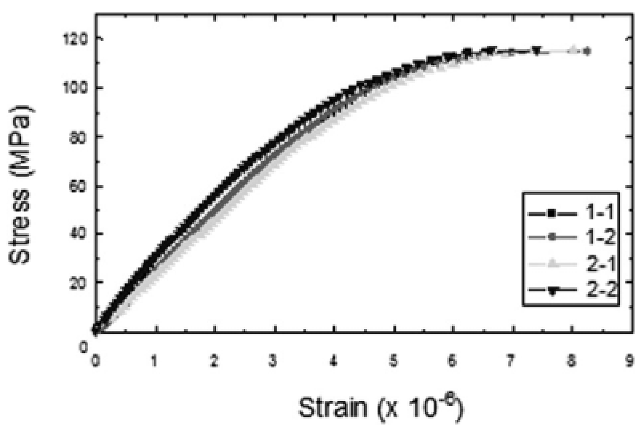

Figure 6 σ-ε Curve [specimen 3 (air dry)].

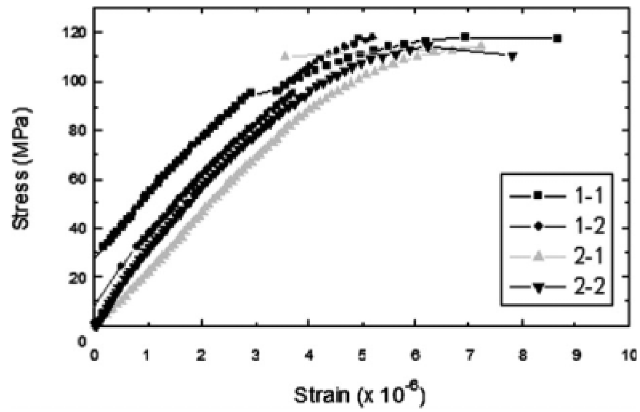

Figure 7 σ-ε Curve [specimen 2 (air dry)].

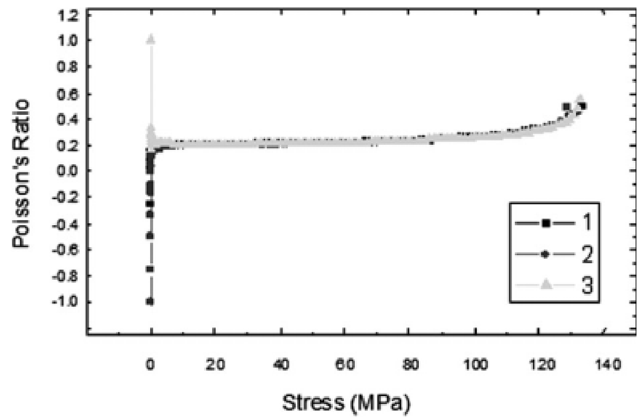

Figure 8 Relation between compressive strength and Poisson's ratio (3 heated).

Poisson's ratio is significantly big. For polymer concrete, the strain against the maximum stress is about 0.006–0.007 but it is 0.003–0.004 for cement concrete. These results indicate that the strain of polymer concrete is quite high than that of cement concrete. This result makes it possible to forecast that the

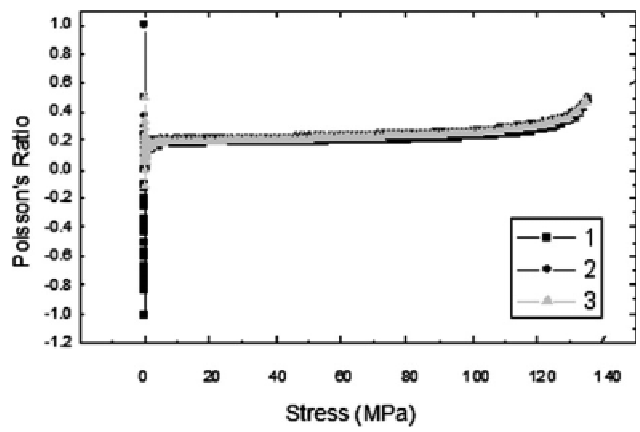

Figure 9 Relation between compressive strength and Poisson's ratio (4 heated).

TABLE XIII
Test Result of Modulus of Elasticity

Specimens	Test results ($\times 10^4$ MPa)	Mean ($\times 10^4$ MPa)
Polymer photo-manhole Type IV (heated)	2.9, 2.8, 3.0	2.9
Polymer photo-manhole Type IV (air dry)	2.7, 2.9, 2.8	2.8
Polymer photo-manhole Type III (heated)	2.8, 3.0, 2.8	2.9
Polymer photo-manhole Type III (air dry)	2.6, 2.4, 2.5	2.5
Polymer photo-manhole Type II (air dry)	3.3, 2.5, 2.8	2.9

toughness would be high, which is a good result for manhole structure.

CONCLUSION

This study was performed to check the feasibility of concrete polymer manhole through a development test of high strength polymer concrete and prepare fundamental data for design to solve the problems of the existing cement concrete manhole. Conclusions in this study are as follows:

1. In this study, specific gravity of polymer concrete was 2.30 in average and its absorption capacity was 0.39% and its unit weight is not much different from that of cement concrete. However, its lower absorption capacity would be more advantageous in foundation manholes near by subsurface water.
2. Working-life generally depends on the amount of hardening agent and casting temperature. In this study, it was 63 min in average, which is long enough to establish manholes.
3. In this study, the test results of polymer concrete were shown 127 MPa for compressive strength and 22 MPa for flexural strength, which are strong enough to manufacture a new manhole.
4. The ratio of compressive and flexural strength was 5.7, which was indicated that flexural and tensile strength were relatively large, considering that compressive strength of polymer concrete was not smaller than 120 MPa.

TABLE XIV
Test Result of Poisson's Ratio

Specimens	Test results	Mean
Polymer photo-manhole Type IV (heated)	0.20, 0.22, 0.21	0.21
Polymer photo-manhole Type IV (air dry)	0.22, 0.23, 0.22	0.22

Conclusively, the high strength polymer concrete that is the most important issue in development of polymer concrete manhole could be made and fundamental studies for such development were finished through test results.

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