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Reinforcement and Dynamic Behavior of Polymer Concrete for Structural Use

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ABSTRACT

The use of reinforcing steel restrains the shrinkage of polymer concrete during hardening, causing losses in the bending strength. One solution to minimize such losses is the use of a shrinkage-reducing admixture. The authors investigated the mechanical behavior of steel-reinforced polymer concrete containing a shrinkage-reducing admixture and found that losses in its bending stress can be reduced.

Keywords. Reinforcement, Polymer concrete, Reinforcing bar, Shrinkage-reducing admixture

INTRODUCTION

Unsaturated polyester resin (UP) is used for polymer concrete as a binder. When using polymer concrete as a constructional material, reinforcement with steel is one method to control brittle failure under bending loads. However, steel reinforcement restrains the volumetric shrinkage of the resin during hardening, causing internal tensile stress. This reduces the flexural proof stress. Such polymers as polystyrene are therefore added to control the tensile stress during hardening. Polystyrene, a thermoplastic polymer, is used as a shrinkage-reducing admixture. However, such addition is prone to problems such as defects during production and execution, which have yet to be fully solved.

In this research, the authors attempted to reinforce polymer concrete with steel bars to control its brittle failure in flexure. This paper reports on experimental investigation into their effects in mitigating the internal tensile stress and reducing the losses in the proof stress.

EXPERIMENT

Experiment Outline. Three levels were selected for each of the experiment factors: the dosage of the shrinkage-reducing admixture and the bar diameter. Table 1 gives the factors and levels.

An orthophthalate-type UP was used as the binder. Coarse and fine aggregates were macadam 7 from Sano, Tochigi Prefecture and quartz sand from Kajima, Ibaraki Prefecture, respectively. Calcium carbonate from Nanmoku, Gunma Prefecture, was used as the filler. A styrene monomer solution of polystyrene with a viscosity of 7 – 11 dPa·s and volatile matter content of 68 – 72% was used as a shrinkage-reducing admixture. Tables 2 and 3 give the types, qualities and characteristics of materials and the mixture proportions of polymer concrete, respectively.

The shapes and dimensions of specimens are as follows: Prismatic specimens 200 by 200 by 200 mm were used for internal temperature rise measurement. This size was selected so as not to be affected by room temperature. Beam specimens 60 by 60 by 240 mm as specified in JIS were used for measuring the strain of reinforcing bars in relation to bending stress. For measuring the shrinkage of polymer concrete, cylindrical specimens 100 mm in diameter and 500 mm in height were used in consideration of the measurement accuracy and the amount of shrinkage. After placing, specimens were air-cured at 20°C for 48 h. Three specimens were prepared for each test case. The dimensions of these specimens were selected to eliminate the effect of ambient temperature.

Table 1. Experiment factors and levels

Factor	Level	
	Temperature change	Kind of steel bar
Diameter of steel bar (mm)	—	0, 6, 13
Shrinkage reducing agent (%)	0, 15, 30	
Note: (%) denotes the mass ratios of the shrinkage reducing agent to the amount of UP.		

Table 2. Materials

Material		Type	Properties/Description
Bonding material		Unsaturated polyester resin (UP)	Thermosetting polymer,orthophthalate system
Coarse aggregate		Macadam7	Density: 2.63g/cm^3, Water absorption: 0.67%, F.M.: 5.26
Fine aggregate		Quartz sand	Density: 2.61g/cm^3, Water absorption: 0.80%, F.M.: 1.71
Mixture material		Calcium carbonate	Density: 2.60g/cm^3
Mixture agent	Shrinkage reducing agent	Polystyrene	Cure shrinkage of thermoplastic polymer and polymer is eased and controlled.
	Catalyst	Cobalt naphthenate	Promotion of cobalt salt and shortening / hardening exothermic temperature of cure time
	Initiator	Methyl-ethyl-ketone par oxide	Normal temperature hardening agent
Chemical admixture for viscous fall		Styrene	Materials of polystyrene

Table 3. Mixture proportions

Sign	Diameter of reinforcing bar (mm)	Binder (%)	Aggregate		Additive (filler) (%)	Chemical admixture		
			Coarse agg. (%)	Fine agg. (%)		Shrinkage reducing agent (phr)	Catalyst (phr)	Initiator (phr)
0-0	0	10	50	20	20	0	0.5	1
0-15		8.5				15		
0-30		7.0				30		
6-0	6	10				0		
6-15		8.5				15		
6-30		7.0				30		
13-0	13	10				0		
13-15		8.5				15		
13-30		7.0				30		

Notes 1: In the case of 6-15, 6 denotes the bar diameter and 15 denotes the dosage of the shrinkage reduction agent (%).

2: (%) denotes percentage by mass of the total and phr denotes percentage by mass of polymer.

Test Methods and Items. The internal temperature rise of polymer concrete was measured by thermocouples embedded in the central part of prismatic test specimens. Strain introduced into polymer concrete and reinforcing bars by cure shrinkage was measured using beam test specimens. One reinforcing bar (round bar) with a diameter of 0, 6, or 13 mm was embedded in the cross-sectional center of each beam test specimen. The reinforcement ratios are 0, 0.8, and 3.7%, respectively. The restraining stress introduced into reinforcing bars was measured by strain gages attached to the center of the bars. At the time of bending testing, the strain of reinforcing bars and polymer concrete was measured using similar specimens. Measurement was continued for 48 h after placing until flexural cracking occurred in the beam specimens. Three specimens each were prepared for 9 cases of different bar diameters and dosages of the shrinkage-reducing admixture.

The shrinkage of polymer concrete cannot be accurately measured by gluing strain gages onto concrete surfaces after gelation, as shrinkage begins earlier. To cope with this problem, polymer concrete was placed in molds with inside surfaces coated with a mold release agent. The displacement was measured by placing a polyethylene cover 10 mm in thickness, to which a dial displacement gage was attached, on the placing surface of polymer concrete. The ambient temperature at the time of measurement was 21.5°C. Figure 1 shows the test apparatus and beam specimen. Table 4 shows the test items and the test devices.

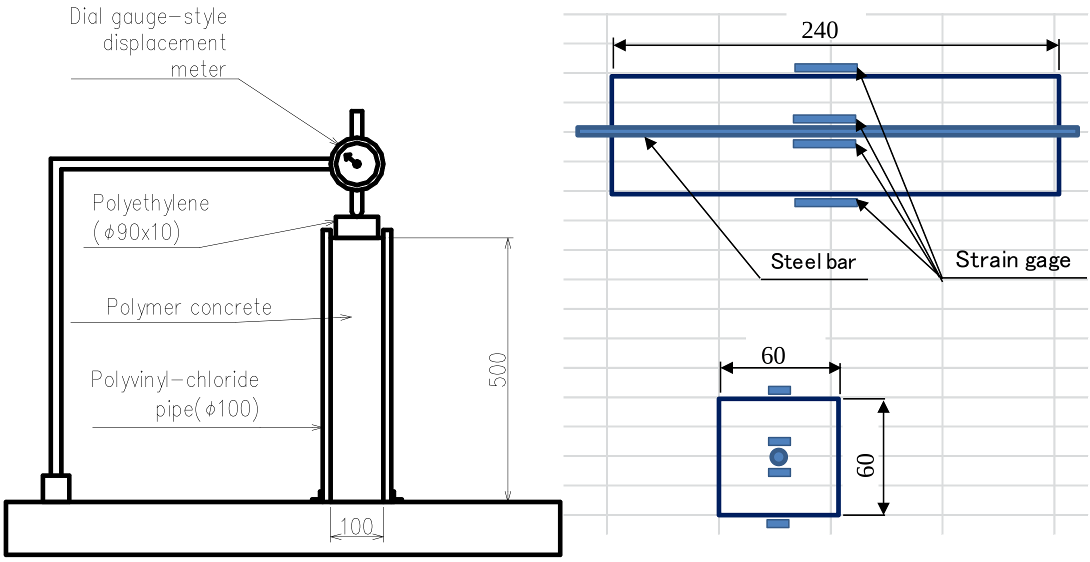

Figure 1. Device and test specimen

Table 4. Test items and test devices

Test item	Test device
Flexural strength	Compression, bending testing machine
Temperature	Thermocouple
Strain of steel bar	Strain gage
Cure shrinkage of polymer concrete	Dial gauge-type displacement meter

RESULTS AND DISCUSSION

Temperature Change of Polymer Concrete. Polymer concrete generates heat during hardening. Figure 2 shows changes in the internal temperature of polymer concrete over time beginning with the addition of an initiator to the resin. The temperature of polymer concrete containing no shrinkage-reducing admixture rapidly increases after the addition of the initiator, rising 16.9°C to hit the peak of 38.4°C 2.3 h later. It rapidly drops for 2 h and slowly decreases thereafter. Gelation began 34 min from the beginning of measurement.

When the dosage of the shrinkage-reducing admixture is 30% by mass of the resin, the internal temperature of polymer concrete rapidly increases after the addition of the initiator, rising 13.0°C 2.5 h later to hit the peak of 34.5°C. It then rapidly decreases for around 2 h and slowly decreases thereafter. An increase in the dosage of the shrinkage-reducing admixture restricts the increase in the internal temperature, due to a reduction in the content of UP, the binder. Within the range of the present mixture proportions, an increase in the shrinkage-reducing admixture dosage of 10 percentage points is found to lead to a reduction in the internal temperature of approximately 2°C.

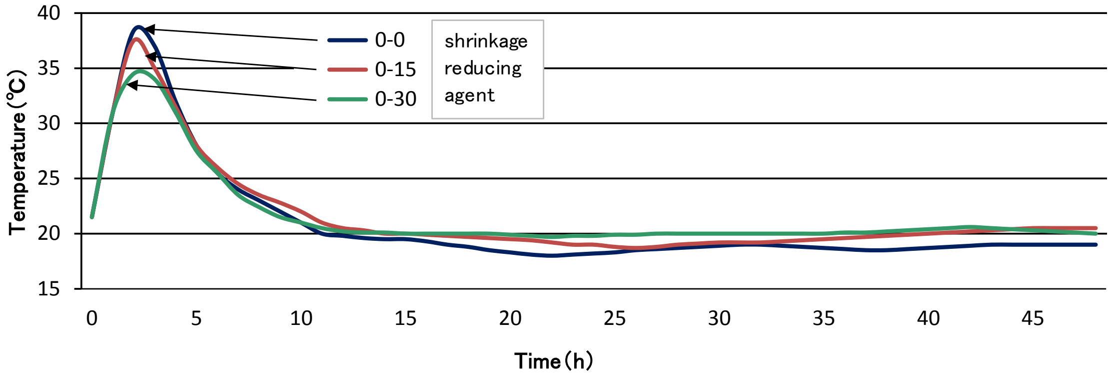

Figure 2. Internal temperature change of polymer concrete

Strain of Polymer Concrete and Reinforcing Bar. Figure 3 shows the experimental results of the cure shrinkage strains of polymer concrete and reinforcing bars. Whereas the hardening strain of polymer concrete occurs in the first 2 to 3 h, the strain of reinforcement is slightly delayed, presumably due to the effect of the hardening of polymer concrete. The restraint by polymer concrete develops only after the concrete hardens to the extent that it affects the strain of reinforcement. In the case of unreinforced specimens with a shrinkage-reducing admixture dosage of 30% ("0-30 (shrink)" in the figure), the admixture begins to take effect approximately 4 h later, mitigating the shrinkage by around 400 μ from the maximum level of 1,750 μ. The strain of both 6 mm and 13 mm bars once turns to compressive and then reverses to tensile. With a shrinkage-reducing admixture dosage of 0% and 15%, the strain is compressive throughout. the test and tends to increase with a lower reinforcement ratio in either case. The equilibrium point with no tensile or compressive stress exists between the shrinkage-reducing admixture dosages of 15% and 30%.

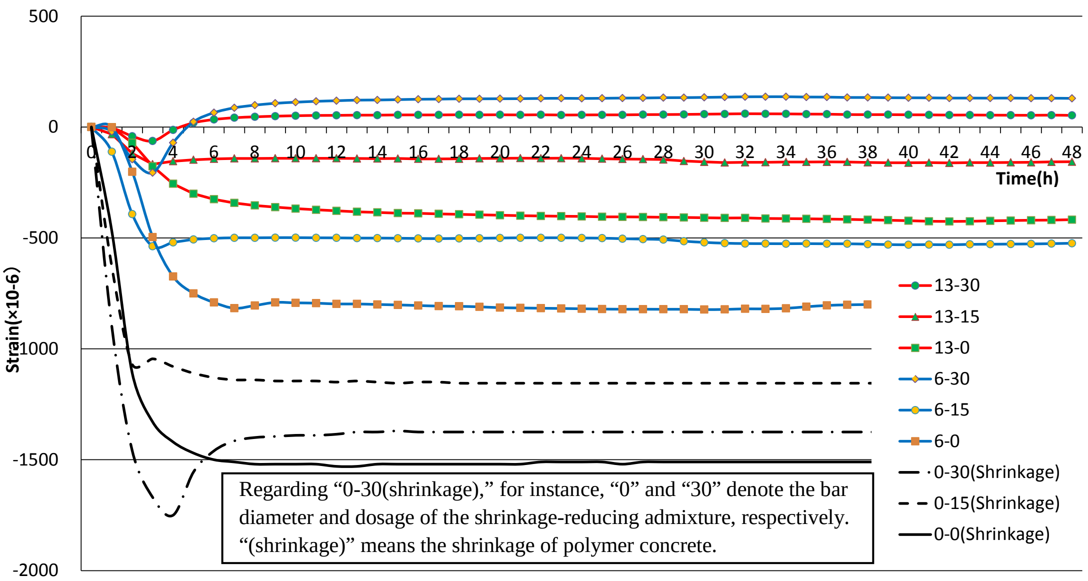

Figure 3. Strain of polymer concrete and reinforcing bar

When reinforced with a steel bar, the flexural strength of polymer concrete decreases due to the restraint of the bar. However, it is inferred that such strength loss of steel-reinforced polymer concrete can be prevented by adjusting the dosage of a shrinkage-reducing admixture.

Figure 4 shows the strain of polymer concrete and reinforcement measured during bending testing using specimens containing a shrinkage-reducing admixture at a dosage of 30%. The tests were continued to failure of specimens. The strain of unreinforced specimens at failure is 1,200 μ on the tension side of the specimens, with the load at that time being 2,300 kg. When reinforced with a steel bar, the strain on the tension side of the specimens is 1,000 μ regardless of the bar diameter. The strain on the compression and tension sides of 6 mm diameter bars is 50 μ and 140 μ, respectively, whereas that of 13 mm diameter bars is 170 μ and 200 μ, respectively. A larger reinforcement ratio thus led to a larger strain.

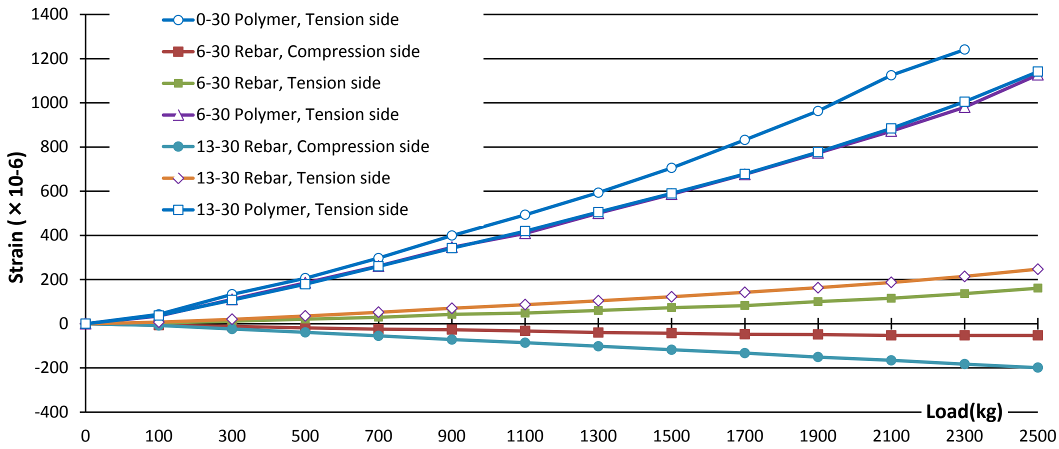

Figure 4. Strain of bending strength test

CONCLUSIONS

The results of this study are summarized as follows:

(1) When the thickness of a polymer concrete member is 200 mm, the internal temperature of the member decreases by approximately 2°C per addition in the shrinkage-reducing admixture dosage of 10 percentage points by mass of the resin.

(2) A dosage of a shrinkage-reducing admixture of 30% by mass of the resin led to a reduction in the shrinkage strain of polymer concrete of approximately 400 μ.

(3) Losses in the flexural strength of reinforced polymer concrete, due to reinforcing bars restraining the matrix, can be minimized by addition of a shrinkage-reducing admixture with a dosage of 15% to 30%.

REFERENCES

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