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Deformation behavior of acrylic polymer concrete: Effects of methacrylic acid and curing temperature

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HIGHLIGHTS

- The deformation behavior of acrylic PC was investigated to evaluate its viability as a structural/repair material.
- Ultimate setting shrinkage increased as the MAA content and curing temperature increased.
- CTE of acrylic PC tended to decrease with the increased MAA content.
- MAA was quite effective in improving mechanical properties of acrylic PC.
- This study proposed an elastic modulus prediction model for acrylic PC.

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ABSTRACT

Objective: This study explores the deformation characteristics of acrylic polymer concrete (PC) to examine the viability of using acrylic PC as an infrastructure material.
Materials: An acrylic resin with benzoyl peroxide (BPO) initiator and N,N-dimethylaniline (DMA) accelerator was used as a binder for PC. As an auxiliary accelerator, methacrylic acid (MAA) was employed.
Methods: A series of laboratory experiments was performed to measure the setting shrinkage, coefficient of thermal expansion (CTE), and stress-strain relation of acrylic PC. Experimental variables were MAA contents (0, 5, and 10 parts per hundred parts of resin (phr)) and curing temperatures (10, 20, and 30 °C).
Results: The result showed that the ultimate setting shrinkage tended to increase as the MAA content and curing temperature increased. Furthermore, it was found that MAA had a significant effect on the rate of setting shrinkage development especially at very early ages. The CTE of acrylic PC tended to decrease with the increased MAA content. The experimental results also indicated that compressive strength, ultimate compressive strain, and modulus of elasticity of acrylic PC were substantially affected by MAA content.

1. Introduction

It is widely accepted that polymer concrete (PC) has excellent strength characteristics and durability, especially in terms of chemical resistance as well as freezing and thawing resistance. Also, PC has unique characteristics such as rapid hardening and easy-to-adjust setting time. In contrast to conventional cement concrete, which commonly requires about 6–7 h to reach its final setting at room temperature [1], PC achieves 80% of its ultimate strength typically within a couple of hours after mixing. Thanks to these characteristics, over the years, the use of PC has been widely encouraged for repair of existing concrete structures such as concrete pavements, bridge decks, floors, parking lots, and airport runways—in which closure time is quite limited—as well as for fabrication of precast components such as sewage pipes, manholes, piles for port, tunnel liner segments, U-shape gutters, and footpath panels.

Typical binders used for PC include epoxy resin, unsaturated polyester resin, and acrylic resin, and it is generally recognized that physical and mechanical properties of PC significantly vary depending on the type of binder used [2–5]. Among them, an

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acrylic resin comprised of methyl methacrylate (MMA) monomer and polymethyl methacrylate (PMMA) has been extensively used owing to its low viscosity, improved workability, and enhanced weatherproofness. In addition to the resin binder, a cross-linking agent such as trimethylopropane trimethacrylate (TMPTMA) is employed to accelerate hardening reactions, along with an initiator and accelerator. However, as the use of a cross-linking agent can increase the material unit cost, a polar monomer such as methacrylic acid (MAA) which functions as an auxiliary accelerator can be added to produce high-strength PC at a less unit cost.

Generally, the deformation behavior of PC is classified into: (a) setting shrinkage (or hardening shrinkage) during initial chemical reactions; (b) thermal deformation due to temperature changes; (c) elastic deformation due to instantaneous loading; and (d) creep deformation due to long-term loading. These deformation components reportedly may cause structural/non-structural cracks and distresses, and in turn, lead to performance degradation of structures [6]. Particularly, when used for repair of existing concrete structures, because of the noticeably different load-independent deformation characteristics between PC (which uses organic polymers as a binder) and Portland cement concrete (which uses cement hydration products as a binder), incompatible movements can occur at the interface between the existing and repaired components, which may increase the probability of debonding failure. In order to prevent and/or resolve these potential problems, it is essential to propose appropriate technical measures to control setting shrinkage and thermal deformations.

Considering these issues, in this study, the deformation characteristics of acrylic PC such as setting shrinkage, thermal expansion, and compressive stress–strain relation at different levels of MAA content and curing temperature are experimentally addressed to evaluate the viability of using acrylic PC as a structural/repair material for infrastructures.

2. Materials and methods

2.1. Materials

2.1.1. Binder

2.1.1.1. Acrylic resin. An acrylic resin was produced by dissolving PMMA powder into MMA monomer which is typically a clear liquid with excellent weatherproofness and chemical resistance to acid, alkali, and salts. For this procedure, a premium hotplate stirrer with 1500 rph (Model: MSH-20A) was used. The stirring operation was continued for an hour when PMMA was 10% and for 3 h when PMMA was 30%. The heating temperature was about 60–80 °C. The properties of MMA and PMMA used in this study are shown in Table 1.

2.1.1.2. Initiator and accelerator. In the present study, benzoyl peroxide (BPO) and N,N-dimethylaniline (DMA) were used as an initiator and accelerator, respectively. The amount of BPO and DMA was fixed to 2 parts per hundred parts of resin (phr) for each mixture. Tables 2 and 3 present the complete details of BPO and DMA used, respectively.

2.1.1.3. Auxiliary accelerator. This study employed MAA as an auxiliary accelerator in place of TMPTMA which is a cross-linking agent. MAA, a type of polar monomer, generally improves the compatibility with other resins and accelerates hardening reactions. Plus, it is well known that MAA effectively improves the strength characteristics of PC [5]. In this study, the amount of MAA varied between 0 and 10 phr. The properties of MAA used are reported in Table 4.

Table 2
Properties of BPO.

Melting point (°C)	Molecular weight (g/mol)	Appearance
104–105	242.23	Crystalline solid, white

Table 3
Properties of DMA.

Density (25 °C)	Boiling point (°C)	Melting point (°C)	Molecular weight (g/mol)	Appearance
0.942	193–194	1.5–2.5	121.18	Yellow liquid

Table 4
Properties of MAA.

Density (20 °C)	Viscosity (20 °C, mPa s)	Molecular weight (g/mol)	Appearance
1.01	1.3	86.1	Colorless liquid

Table 5
Physical properties of aggregate.

Size (mm)	Apparent density	Unit weight (kg/m^3)	Fineness modulus	Water content (%)	Organic impurities
0.08–8	2.64	1648	3.09	<0.1	Nil

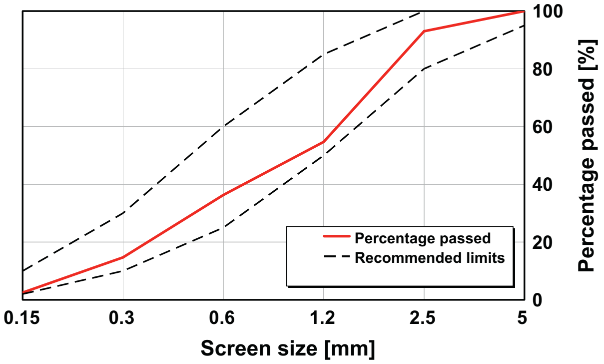

Fig. 1. Aggregate gradation curve.

2.1.2. Aggregate and filler

Silica sand with maximum aggregate size of 5 mm was used as aggregate, and its physical properties and gradation curve are shown in Table 5 and Fig. 1, respectively. As a filler, ground calcium carbonate, which hardly absorbs resins, was employed. Fundamental properties and chemical compositions of the filler used are summarized in Table 6.

2.2. Test methods

2.2.1. Mixture proportions of polymer concrete

The mixture proportions of acrylic PC determined by preliminary tests on workability and strength are shown in Table 7. In this study, the binder content was fixed to 12 wt.%, while the MAA content varied from 0 to 10 phr with a 5 phr increment.

Table 1
Properties of MMA and PMMA.

Materials	Density (25 °C)	Viscosity (20 °C, mPa s)	Molecular weight (g/mol)	Appearance
MMA	0.942	0.56	100	Colorless liquid
PMMA	1.19	–	ca. 250,000	Transparent solid