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Mechanical properties of acrylic polymer concrete containing methacrylic acid as an additive

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HIGHLIGHTS

- ▶ Effect of methacrylic acid (MAA) on mechanical properties of acrylic polymer concrete was investigated.
- ▶ The higher the MAA content, the greater the mechanical properties of acrylic polymer concrete.
- ▶ Excellent mechanical properties were achieved even at a low curing temperature solely by adding MAA.

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ABSTRACT

This study experimentally examines the effect of methacrylic acid (MAA) on the mechanical properties of polymer concrete using methyl methacrylate (MMA)–polymethyl methacrylate (PMMA) as a binder in order to develop the polymer concrete that can be used at low temperatures. To achieve this aim, a series of laboratory tests were conducted to measure the mechanical properties such as compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, and Poisson's ratio. Along with the mechanical properties, the hardening time and working life were also investigated. As a result, adding MAA was found to be effective for ensuring the working life at a low temperature and improving the strengths at an early stage, especially within the first 12 h. Furthermore, research revealed that the higher the MAA content, the greater the modulus of elasticity and Poisson's ratio. In conclusion, acrylic polymer concrete with excellent mechanical properties could be achieved even at a temperature as low as −20 °C solely by adding MAA.

1. Introduction

Polymer concrete has been widely used for repair and overlay of deteriorated concrete pavements, airport runways, and bridge decks as well as fabrication of precast products due to its well-known advantages in hardening time, freezing and thawing resistance, corrosion resistance, compressive strength, splitting tensile strength, flexural strength, and bond strength [1]. To date, extensive research studies have been made on the binders for polymer concrete such as unsaturated polyester resin [1,2–4], gamma irradiation-treated unsaturated polyester resin [5–7], unsaturated polyester resin incorporating methyl methacrylate (MMA) [8–10], epoxy resin [11], sulfur [12], unsaturated polyester resin from recycled PET [13], and sodium silicate [14]. Further studies have been conducted on polymer modified concrete [15] and polymer impregnated concrete [16]. Also, there have been several research studies on the polymer concrete using an MMA–polymethyl methacrylate (PMMA) system as a binder [2,3,17,18], but most of them focused on the polymer concrete employing trimethylopropane trimethacrylate (TMPTMA) as a cross-linking agent. Very few research efforts have been made on the MMA–PMMA polymer concrete using MAA, one of the polar monomers serves as an auxiliary accelerator.

Polymer concrete with acrylic resin (hereinafter, *acrylic polymer concrete*), investigated in this study, is rapid set and typically experiences slight changes in mechanical properties once hardened. The acrylic polymer concrete has several benefits as a structural material due to its ease of viscosity adjustment to a variety of levels, excellent weather, chemical and abrasion resistances, and high bond strength. However, the MMA monomer, a binder employed in this study, typically has a low viscosity (0.56 mPa s), slow hardening time, and high evaporation rate, which prevents the MMA monomer from being used alone for polymer concrete. Accordingly, the agents such as TMPTMA, tetraethylene diacrylate (TTEGDA), and glycerol methacrylate (GM) which have two or more unsaturated double bonds to a single molecule are used as a cross linker to improve the strength and accelerating the hardening

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Table 1
Properties of MMA and PMMA.

Materials for binder	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

Table 2
Properties of BPO.

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

time. In addition, the thermoplastic resins such as polymethyl methacrylate (PMMA) and polystyrene (PS) are used not only to minimize shrinkage and evaporation but also to increase strengths.

Generally, the type and addition amount of initiator and accelerator, curing temperature, and aggregate quality are the elements affecting the hardening time and mechanical properties of polymer concrete. The curing temperature is a critical factor determining the hardening and strength development characteristics [19]. For this reason, in case of winter concreting, heating aggregates or protecting concrete with polyethylene sheet is typically required to ensure the proper curing temperature.

In this study, the acrylic polymer concrete using MMA–PMMA as a binder and MAA as a catalyst supplement was fabricated and tested. The present study aims at examining the effects of MAA on the mechanical properties such as compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, and Poisson's ratio at different levels of curing temperature. The findings of this study could be used as useful data for repair of existing infrastructures and manufacturing of precast products.

2. Material and method

2.1. Material

2.1.1. MMA binder

In this study, MMA binder was produced by dissolving PMMA powder in MMA monomer. The PMMA is a thickening agent, which increases the viscosity of MMA monomer by polymerization. Table 1 shows the properties of MMA and PMMA used.

2.1.2. Initiator

Benzoyl peroxide (BPO) is a radical polyinitator and produces a polymer by forming a new radical when binding to a monomer. Table 2 summarizes the properties of BPO used.

2.1.3. Accelerator

N,N-Dimethylaniline (DMA) is an accelerator which helps polymerization even at a low temperature. Table 3 shows the properties of MMA used.

2.1.4. Auxiliary accelerator

Auxiliary accelerator (MAA) is a polar monomer enhancing the compatibility with other types of resins. Also, MAA functions as a supplementary catalysis, helping the hardening reaction as well as the strength improvement. The properties of MAA used in this study are summarized in Table 4.

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	Yellowish liquid

Table 4
Properties of MAA monomer.

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 crushed silica stone.

Size (mm)	Apparent density	Bulk density	Unit weight (kg/m^3)	Fineness modulus	Water content (%)	Organic impurities
0.08–8	2.64	2.62	1648	3.09	<0.1	Nil

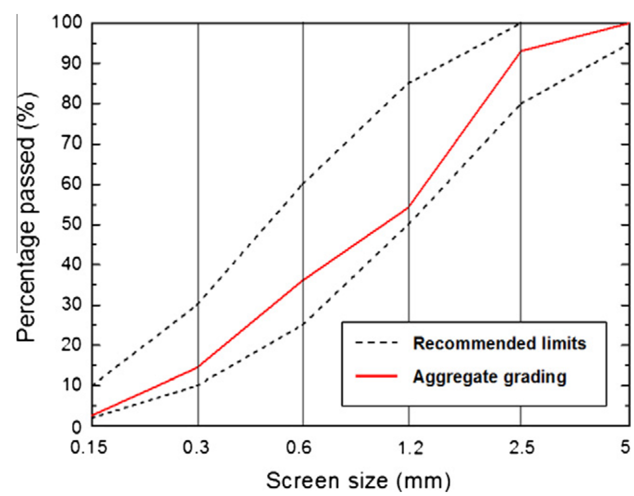

Fig. 1. Gradation curve of aggregate.

Table 6
Properties of heavy calcium carbonate.

Specific gravity (g/cc)	Absorption (cc/g)	Water content (%)	pH	Mean grain size (μm)	Retained percentage of 325 mesh sieve
0.75	0.20	≦0.3	8.8	13	0.03

2.1.5. Aggregates and filler

If aggregate absorbs water, the bond strength between the binder and aggregate weakens, resulting in strength reduction of polymer concrete. This is because phase separation occurs as the polymer binder is hydrophobic. Accordingly, it is necessary to keep the aggregates' moisture content below 0.1% prior to mixing. As polymer concrete is a high strength material, the strength of aggregate itself is also important. The aggregate used in this study is crushed silica stone, and its mechanical properties and gradation curve are indicated in Table 5 and Fig. 1, respectively.

Heavy calcium carbonate was used as the filler to ensure the good workability. The mechanical properties and chemical compositions of the filler used are shown in Tables 6 and 7, respectively.

2.2. Test method

2.2.1. Binder formations and mixture proportions of polymer concrete

The optimal mixture proportions can be obtained by maximizing the amount of aggregate and filler and minimizing the amount of binder, as long as the required workability and strength are ensured. In this study, the binder composition ratio and concrete mixture proportions were determined based on the preliminary tests on the polymer concretes with different MMA–PMMA ratios and volume of binder. The binder composition ratios and polymer concrete mixture proportions determined are summarized in Table 8.