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Strength development characteristics of UP-MMA based polymer concrete with different curing temperature

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HIGHLIGHTS

- Effects of curing temperature, age, and unsaturated polyester (UP)-methyl methacrylate (MMA) ratio on strengths were examined.
- The strengths were reduced by 32.8% on average as the curing temperature decreased from 20 to −20 °C.
- The strengths significantly developed within the first 6 h.
- The strengths tended to decrease as the MMA content increases.
- This study proposed strength predictive models based on maturity concept.

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ABSTRACT

In this study, the effects of curing temperature, age, and unsaturated polyester (UP)-methyl methacrylate (MMA) ratio on the strength development characteristics of UP-MMA based polymer concrete are investigated. This study distinguishes itself from previous research in that MMA monomer was used to adjust the viscosity of UP resin, instead of styrene monomer. The result showed that as the curing temperature decreased from 20 to −20 °C, the strengths were reduced by 32.8% on average. Also, research revealed that the UP-MMA based polymer concrete significantly develops its strengths within the first 6 h, and the average strength at 72 h was 86.6% of the strength at 168 h. As the MMA content increases, the strengths of UP-MMA based polymer concrete tended to decrease. However, the effect of MMA on the strength reduction was less significant than that of curing temperature. Also, this study proposes a strength predictive model based on the maturity concept. The result of regression analysis between the measured strengths and computed maturity yielded high coefficients of determination of 0.91–0.97, validating the applicability of the maturity model suggested by Ohama. The findings of this study could be utilized as important data for field applications as well as manufacturing of precast products.

1. Introduction

Polymer concrete is a construction material composed of organic polymer, inorganic aggregate, and filler, and is typically used for special applications requiring fast consolidation and chemical resistance [1]. Polymer concrete has several well-known advantages over cement concrete in terms of high early strength characteristics and good adhesion property, which enables the polymer concrete effectively used for restoration of portland cement concrete pavements and airport runways [2,3]. Furthermore, polymer concrete can be utilized as an overlay material for improving the service life of bridge decks [4].

As the binders for polymer concrete, polyester resin [1,5–9], epoxy resin [4,8], and acrylic resin [2,3,9,10] have been mainly used, and their physical and mechanical properties significantly vary depending on the amount and chemical compositions of binders. Also, depending on the supplementary materials such as aggregate, filler, and chopped glass fiber and the additive such as pigment, the polymer concrete with various features can be produced [4,9].

Furthermore, polymer modified concrete [11], which uses the admixtures such as latex and emulsion for improving the properties of cement concrete, and polymer impregnated concrete [12], the composite material produced by impregnating the low-viscosity monomers into the hardened cement concrete, have been used. In recent years, research efforts have been made on the silicate polymer concrete which uses water-soluble sodium silicate and potassium glass as binders [13]. However, very limited research

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studies [14] have been conducted on the polymer concrete incorporating unsaturated polyester (UP) resin and methyl methacrylate (MMA) as binders.

Polymer concrete with UP resin has advantages in its cost effectiveness, short curing time, high strength, and ease of controlling hardening time via the use of initiator and accelerator. However, it also has some shortcomings such as decreased workability due to its high viscosity (300 mPa s at room temperature), occurrence of cracking due to large setting shrinkage, and degradation of weatherability under ultraviolet rays. Accordingly, if UP resin is solely used for polymer concrete production, a large amount of binder is typically required to ensure good workability. To resolve this viscosity issue, styrene monomer can be added, but the excessive use of styrene monomer can cause problems such as setting shrinkage and strength reduction. On the other hand, MMA monomer employed in this study typically has a low viscosity (0.56 mPa s), delayed hardening time, and a high evaporation rate, which prevents the MMA monomer from being used alone for polymer concrete without a thickening agent. However, if MMA monomer is used in combination with UP resin, not only can the described shortcomings be compensated but also the high strengths can be achieved even at a low temperature, and thus the external heat energy required for hardening can be saved. From a practical standpoint, the UP-MMA based polymer concrete has advantages in reducing the material cost since the desired workability can be achieved without excessive use of binder. In addition, volume stability during construction can be ensured with the decreased setting shrinkage, and the cross-sectional dimensions of a member can be markedly reduced due to the high strength characteristics.

The strength of polymer concrete depends on many factors such as the type and amount of binders, mixing method, and curing condition. Also, the amount of initiator and accelerator and curing temperature are important factors. Based on the laboratory experiments and data interpretations, this study primarily examines the effects of curing temperature (−20, −10, 0, 10, and 20 °C), age (3, 6, 12, 24, 48, 72, 120, and 168 h), and UP-MMA ratio (8:2, 7:3, and 6:4) on the compressive, splitting tensile, and flexural strength development characteristics of polymer concrete using UP-MMA as binders (hereinafter, *UP-MMA based polymer concrete*). Also, the present study proposes a maturity-based strength prediction model [15–17] to provide the fundamental information for job-site applications and design and production of precast products.

2. Materials and methods

2.1. Materials

2.1.1. Binder

2.1.1.1. UP resin. UP resin is a polymer compound; monomers of its molecule are polymerized by ester bonds. UP resin is easy to handle, and its curing time can be adjusted depending on the addition rate of the initiator and accelerator. The

Table 1
Properties of UP resin.

Density (25 °C)	Viscosity (25 °C, mPa s)	Acid value	Styrene content (%)
1.13	300	20.0	40

Table 2
Properties of MMA monomer.

Density (25 °C)	Viscosity (20 °C, mPa s)	Molecular weight (g/mol)	Appearance
0.9420	0.56	100	Transparent

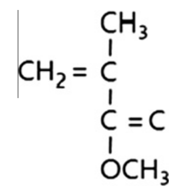

Fig. 2. Constitutional formula of MMA monomer.

Table 3
Properties of MEKPO.

Component	Specific gravity (25 °C)	Active oxygen
MEKPO 55% DMP 45%	1.12	10.0

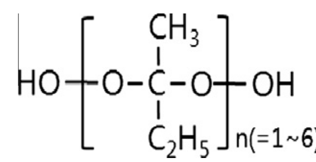

Fig. 3. Constitutional formula of MEKPO.

Table 4
Properties of DMA.

Density (25 °C)	Boiling point (°C)	Melting point (°C)	Molecular weight (g/mol)	Appearance
0.9420	193–194	1.5–2.5	121.18	Oily liquid

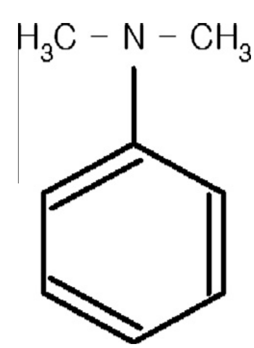

Fig. 4. Constitutional formula of DMA.

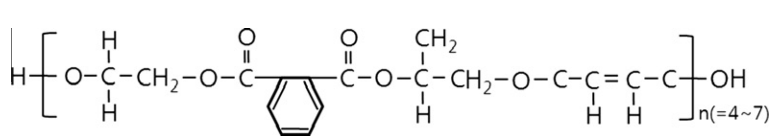

Fig. 1. Constitutional formula of ortho-type UP resin.