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Evaluation of effectiveness of methyl methacrylate as retarder additive in polymer concrete

Nur Hafizah A. Khalid [a], Mohd Warid Hussin [a], Mohammad Ismail [b], Norazah Basar [c], Mohamed A. Ismail [d], Han-Seung Lee [d,*], Azman Mohamed [e]

[a] Construction Research Centre (UTM CRC), Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor, Malaysia
[b] Department of Structure and Materials, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor, Malaysia
[c] Department of Chemistry, Faculty of Science, Universiti Teknologi Malaysia, 81310 Johor, Malaysia
[d] School of Architecture and Architectural Engineering, College of Engineering Sciences, Hanyang University, ERICA Campus, Republic of Korea
[e] Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor, Malaysia

HIGHLIGHTS

- Methyl methacrylate performs effective retarder additive for polymer concrete in room ambient of 30 ± 2 °C.
- Retarder additive of methyl methacrylate could improve properties of polymer concrete.
- Retarder additive of methyl methacrylate was not affected curing process of polymer concrete.

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ABSTRACT

It is a known fact that most thermoset resins are very sensitive to hot temperature, which hinders its ability to produce polymer-based products in a large scale. This study aims to investigate the potential of manufacturing polymer concrete in ambient room temperature of 30 ± 2 °C. A laboratory test was conducted with the introduction of polyester retarder additive into polyester resin formulation. All tests were carried out strictly in ambient room temperature (30 ± 2 °C). For comparison purpose, polyester resin without retarder additive was prepared as the control formulation under identical condition. Visual inspection was done on the fresh working life of polyester resin with 0%, 0.1%, 0.15%, and 0.2% of retarder additive in two different types of polyester resin-isophthalic and orthophthalic. Characterization on retarder additive was conducted under X-ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR) and, ^{1}H and ^{13}C Nuclear Magnetic Resonance (NMR). Investigation on the effects of polymer retarder additive on the physical and mechanical properties of polymer resin, polymer blended, and polymer concrete showed that the retarder additive had prolonged the working life and improved properties of polymer concrete. These proved the potential of adding retarder additive in polymer concrete in ambient room temperature of 30 ± 2 °C.

1. Introduction

Thermoset polymer resin such as epoxy, vinyl ester, and unsaturated polyester resin are some typically available commercial resins which are solely used as a binder in polymer concrete (PC) and preferred over thermoplastic polymers due to its higher strength and stiffness [1–3]. However, since epoxy and vinyl ester resins are more expensive than polyester resins, most researches tend to opt for unsaturated polyester resin as a binder [4], even when it is very sensitive toward temperature [4,5]. Due to this reason, PCs are less popular in most Southeast Asia and equatorial countries. High temperatures tend to accelerate the polymerization process [4,6] and jeopardizes the early strength development of PC while causing other related problems such as poor workability, high porosity, honeycomb, and weaker material bonding [7]. This can be solved by casting the PC in a cool room, but this does not make the PCs more cost competitive since the polymer itself is already expensive [8]. Therefore, this paper intends to discuss on a modification done on resin formulation to produce competitive PC with desirable strength.

The main objective of this research, which is to modify polymer binder formulation, is achieved by incorporating retarder additive of methyl methacrylate (MMA) in ambient room temperature.

* Corresponding author. Tel.: +82 314005181.
E-mail address: ercleehs@hanyang.ac.kr (H.-S. Lee).

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Evaluation was initially done on the characterized properties of the retarder additive under X-ray Diffraction (XRD), Fourier Transform Infrared spectroscopy (FTIR) and Nuclear Magnetic Resonance (NMR). Then, the effect of polymer retarder additive on physical properties of fresh working life and hardness of hardened polymer resin was investigated. In this study, binder formulations with and without polymer retarder additive were compared to identify the desired working life of polymer resin at ambient room temperature. The hardness of solidified specimen was observed to verify the curing quality. Further investigation was done on the effect of retarder additive on the physical properties of polymer blended and PC. The test covered the flowability of polymer blended and the physical appearance of PC. Lastly, the potential of PC with retarder additive was investigated in terms of its strength and morphology properties. The findings of this work are expected to provide information to scientists, engineers, fabricators, and manufactures on the production and potential usage of PC.

2. Experimental program

2.1. Materials

2.1.1. Polyester resin and polyester additives

Polyester resins used in PC are commonly unsaturated isophthalic and orthophthalic polyester resins [9]. In this study, polyester additive with 0.5% of promoter of cobalt naphthenate (CoNp) and 1% of cross linker of methyl ethyl ketone peroxide (MEKP) by resin weight were added into the polymer binder formulation. Additionally, methyl methacrylates (MMA) was added as polyester retarder additive into the binder formulation before promoter and cross linker were added. In this study, polymer retarder additive was limited to 0.1%, 0.15%, and 0.2% by resin weight in order to get a sufficient time to cast the PC [10]. In this study, the 'sufficient time' must cover the time during casting, pouring, compacting, and finishing of the fresh concrete. Nevertheless, it should preferably cover the time for cleaning the tools before transferring the sample into the oven for heat curing. General properties of these polyester resins and polymer retarder additive of MMA are presented in Tables 1 and 2, respectively. Even though both isophthalic and orthophthalic polyester resins belong to the family of unsaturated polyester, they have slightly different properties in terms of viscosity and tensile properties. Therefore, the viscosity of fresh polyester resin and the tensile properties of hardened polyester resin for both isophthalic and orthophthalic resins were tested (see Table 1). Viscosity test was conducted according to ASTM D2983 [11]. In this test, the viscosity was measured using a digital Brookfield viscometer in controlled temperature of 25 °C; the SI unit is in centipoises (cPs). Meanwhile, tensile test was carried out according to ASTM D3039 [12] using the Instron universal testing machine with a capacity of 50 kN (with loading rate 0.6 mm/min) to determine the tensile properties; the SI unit here is in megapascal (MPa).

2.1.2. Aggregates and filler

Oven-dried crushed coarse aggregates and river fine aggregates were used and the moisture content was kept consistently below 0.1% for both aggregates. The size of aggregate was limited to 10–12 mm only; smaller sizes of coarse aggregates were preferred to give higher compressive strength, as suggested by Rashid and Mansur [13].

The incorporation of filler from mineral origin such as calcium carbonate and silica sand in PC production remains a debated issue due to the regular availability of resources. However, the combination of wastes as green material in concrete production has been an interesting research topic since the 1980s. This study echoes with such endeavor where palm oil fuel ash (POFA) from agricultural waste was added into PC. POFA was opted as the filler under scrutiny since it could be easily found especially in South East Asia. Additionally, this choice of filler was made based on researchers' preference to use waste resources as an alternative innovative filler [12–14]. POFA, a by-product from palm oil mills, is mostly disposed as agricultural waste in landfills, although it can be potentially transformed to create sustainable and productive materials. Moreover, POFA has attested efficiency in most concrete production when functioning as fillers. In this study, ground POFA that had passed through 45 μm sieve size was used as filler in PC. Fig. 1 and Table 3 give the information of particle size and chemical composition of ground POFA, respectively. Particle size distribution of ground POFA was obtained by using particle size analyzer with wetting method where the particles were dispersed using distilled water to avoid agglomerated condition. While, the chemical composition of ground POFA was obtained under X-ray fluorescence (XRF).

Table 2
Properties of methyl methacrylate (MMA).

Properties	
Density (g/cm^3)	0.94
Molecular mass (g/mol)	100.12
Molecular	$C_5H_8O_2$
Viscosity, 25 °C, 60 rpm (cps)	0.60
Appearance	Transparent liquid

2.2. Mix proportion

PC mixes incorporating ground POFA based isophthalic and orthophthalic polyester resin were used. Two mix proportions of PC were properly designed and manufactured as shown in Table 4. The mix proportions were limited to low binder content of about 12% of resin and 12% of filler. The selection of low binder content is in accordance with previous researchers [14–17]. In this study, the low amount of polymer binder enabled to produce PC with adequate strength at low cost. The coarse aggregates was limited to 30% for all mix proportions and the rest was the fine aggregates. The PC type was labeled using the following notations: Iso-GPOFA; isophthalic PC with ground POFA filler and Ortho-GPOFA; and orthophthalic PC with ground POFA.

2.3. Specimen preparation

To produce the PC, two mixes – dry and wet, were prepared. The dry mix consisted of dry filler and aggregates, which was initially prepared with the required quantities in slow speed mechanical mixer. The wet mix was separately prepared by continuously stirring the resin which was then added with polymer retarder additive, promoter of CoNp, and cross linker of MEKP. After the wet mix was homogenized, it was poured slowly into the dry mix in the concrete mixer. Then, the combined mix was stirred at low speed to avoid air bubbles from being trapped

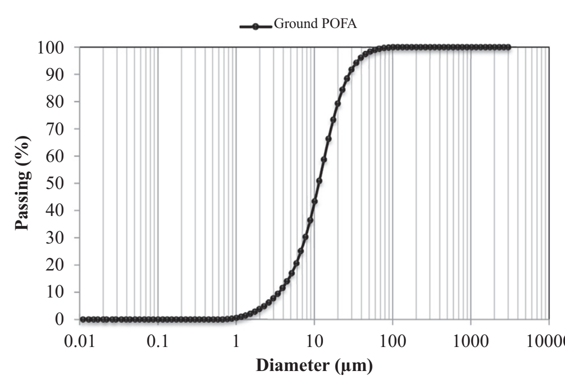

Fig. 1. Ground POFA size distribution.

Table 1
Properties of isophthalic and orthophthalic unsaturated polyester resin.

Properties	Isophthalic polyester resin	Orthophthalic polyester resin
Density (g/cm^3)[a]	1.1	1.1
Styrene monomer content (%)[a]	39–44	39–44
Viscosity (Brookfield), 25 °C, 60 rpm (cPs)[b]	538	426
Tensile strength (MPa)[b] ASTM D3039 [12]	7	6
Tensile modulus (MPa)[b] ASTM D3039 [12]	300	270

[a] Manufacturer data.
[b] Viscosity and tensile properties were tested in this study.