Moisture Sensitivity of Polyester and Acrylic Polymer Concretes with Metallic Monomer Powders

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ABSTRACT: To evaluate the moisture sensitivity of polyester and acrylic polymer concretes with commercial metallic monomer powders, polymer concretes containing different levels of these powders were investigated with respect to the properties of hardened polymer concrete. The mix design was made and optimized for workability, strength, and economy, which depended on the resin viscosity, the intended use, and the additional quantities of the polymeric materials. The investigated properties included the compressive and flexural strengths of hardened polymer concrete. These polymeric materials offer the possibility of using wet aggregates in polyester and acrylic polymer concrete construction. © 2007 Wiley Periodicals, Inc. J Appl Polym Sci 107: 319–323, 2008

Key words: monomers; polyesters; resins; strength

INTRODUCTION

Polymer concrete (PC) is a material made by the replacement of some or all of the cement hydrate binder of conventional mortar or concrete with polymers. This replacement has the effect of strengthening the cement hydrate binder with the polymers. These materials are drawing much attention as high-performance materials in the construction industry and in the mechanical, electrical, and chemical industries.[1]

Generally, normal PC does not work well with wet aggregates.[2] Because most aggregates used to make PC are not absolutely dry, some work has been done on the production of commercial metallic monomers to compensate for it.[2]

Metallic monomer powders, products of S-Company (Houston, TX), contain a metallic element and acrylic functional groups in their molecular structures. They offer the possibility of the use of wet aggregates in PC and widen the application fields of PC repair.

The purpose of this study was to evaluate the moisture sensitivity of hardened polyester and acrylic PC with commercial metallic monomer powders.

EXPERIMENTAL

Materials

Two types of PCs (polyester and acryl) were used in this research.

Resins or liquid monomers

Two different resins were used in making PC. Methyl methacrylate (MMA) and trimethylolpropane trimethacrylate (TMPTMA) were used to formulate MMA PC. MMA is a clear, volatile, and very low viscosity liquid monomer.[3,4] TMPTMA is a trifunctional crosslinking agent that is used to increase the curing rate. Also, polyester PC was made from unsaturated polyester resin,[5] a viscous liquid resin with a styrene monomer concentration of 43.9%.

Initiators

Two types of initiators were used in this research. The initiator used for MMA PC was benzoyl peroxide in the form of a 40% dispersion, and the initiator used in polyester PC was methyl ethyl ketone peroxide (MEKP).

Promoters

Two promoters were used in the PCs. Dimethyl-*para*-toluidine (DMPT) was the promoter used in MMA PC, and cobalt naphthenate (6% concentration by mass) was the promoter used in polyester PC.

Metallic monomer powders

Three metallic monomer powders were used in this study. They were zinc diacrylate (ZDA), zinc dimethacrylate (ZMA), and calcium diacrylate (CDA). They are white powders that do not readily dissolve in resins or monomers.

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TABLE I
Mix Design for MMA PC

Material	Proportion (parts by mass)
MMA monomer	13.1
TMPTMA (SR-350)	0.7
All-purpose sand	86.2
	Concentration with respect to the MMA monomer (%)
Metallic monomer powder	0–15
DMPT	0.18
Dibenzoyl peroxide (40% dispersion)	5
PMMA	3.0[a]

[a] With respect to the total sand.

Aggregate

The aggregate used throughout this study was all-purpose sand. The sand was free from asphalt, dirt, and other organic materials. It was oven-dried by the manufacturer. The moisture concentration of the sand was 0.02%. The fineness modulus of the sand was 2.35.

Additives

In this study, poly(methyl methacrylate) (PMMA) was used for MMA PC as a thickening agent. It was a white substance in the form of small, solid particles. PMMA served as a thickening agent that made the freshly mixed PC more cohesive and workable. It also resulted in a skin on the PC surface soon after placement, which reduced the evaporation of the MMA monomer and minimized the danger of fire.[6]

Concrete mix design

The mix design was optimized for workability and strength without consideration of aggregate gradation because of the use of all-purpose sand.[7]

MMA PC system

The MMA resin-to-aggregate ratio was 13.8 : 86.2 by mass. The proportions of the components by mass are shown in Table I. The concentrations of the metallic monomer powder were 0–15% with respect to the MMA monomer by weight. In this research, the same amounts of the initiator and promoter were used to optimize the working and curing times.

Polyester PC system

The polyester resin-to-aggregate ratio was 20 : 80 by mass. The metallic monomer powder concentrations were 0–20% with respect to the polyester resin. Table II presents the proportions of all components (by mass) used in the polyester PC system.

Program

All PC specimens used in this study were prepared at room temperature (70–75°F).[8]

It is well known that the presence of excess water in the aggregate reduces the mechanical strength of MMA PC.[9,10] To achieve good mechanical properties, moisture in the aggregate should be kept to a minimum. A drying operation to remove moisture from the aggregate for PC would increase the cost. Generally, the maximum amount of water in the aggregate permitted by specifications for MMA PC is in the range of 0.5–1.0%.[11,12]

A study was performed to determine the effects of the addition of metallic monomer powders on the moisture sensitivity for MMA and polyester PC systems. The procedures for this test included prewetting the sand with water at different levels, preparing specimens incorporating different levels of the metallic monomers and moisture, and determining the effects of moisture on the compressive and flexural strengths of PCs with a certain amount of metallic monomer powder.

MMA PC system

An addition of 5.0 wt % metallic monomer (based on resins) to this system was used to evaluate the effects of these monomers on the moisture sensitivity. In other words, all specimens for this test incorporated 5.0 wt % metallic monomer with respect to the MMA monomer.[13] However, the moisture concentration in the specimens varied from 0 to 1.0 wt %, which was based on the oven-dried sand.

Compressive strength versus the moisture. The test was performed at room temperature according to ASTM C 116-90. The specimens were selected from broken portions of the flexure test specimens, which were 2-in. × 2-in. × 12-in. beams.

TABLE II
Mix Design for Polyester PC

Material	Proportion (parts by mass)
Polyester resin	20
All-purpose sand	80
	Concentration with respect to the polyester resin (%)
Metallic monomer powder	0–20
6% cobalt naphthenate	0.48
MEKP	2.5

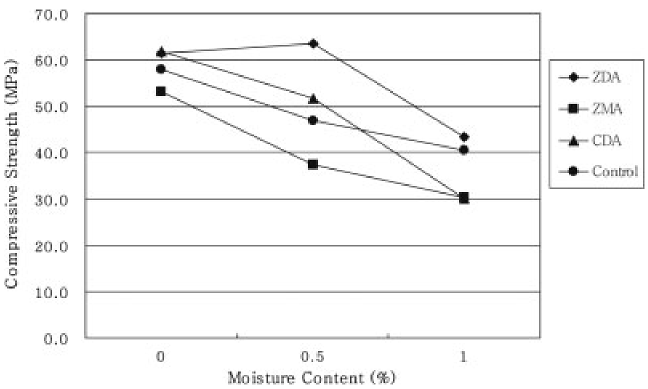

Figure 1 Compressive strength versus the moisture for MMA PC with 5.0 wt % metallic monomer.

Flexural strength versus the moisture. The test used to determine the effect of the moisture on the flexural strength at room temperature was adapted from ASTM C 580-93. The specimens were 2-in. × 2-in. × 12-in. beams.

Polyester PC System

Two sets of tests were performed in this system by the variation of two variables: the moisture concentration and the metallic monomer concentration. First, a study was conducted to evaluate the relationship between the moisture concentration and the strength of the polyester PC through the variation of the moisture concentration; the concentration of the metallic monomer in the specimens was kept constant. The concentration of the metallic monomer was 5.0 wt % with respect to the resins for each of the three metallic monomers.[13] The moisture concentrations were varied from 0 to 1.5% with respect to the weight of the oven-dried sand. Second, a study was performed to evaluate the effect of the metallic monomer concentration on the strength of polyester PC, which incorporated 0.5 wt % moisture with respect to the sand. The metallic monomer concentrations were varied from 0.0 to 15.0% with respect to the resins.

Compressive strength versus the moisture. The test method was adapted from ASTM C 579-91. The specimens were 2-in. cubes cast in molds fabricated from metal.

Flexural strength versus the moisture. The test method used to determine the effect of the moisture on the flexural strength at room temperature was adapted from ASTM C 580-93. The specimens were 1-in. × 1-in. × 12-in. beams.

RESULTS AND DISCUSSION

MMA PC system

Compressive strength versus the moisture

Figure 1 indicates the effect of the sand moisture on the compressive strength of MMA-based PC with and without metallic monomers 7 days after mixing. The compressive strength for the specimens with and without metallic monomers decreased significantly as the moisture concentration increased. However, in comparison with the control, the batch with ZDA had a much higher compressive strength and exhibited excellent resistance to moisture. At a 0.5% moisture level and an age of 7 days, for example, an increase of 50% in the compressive strength over the control was obtained because of the introduction of 5.0% ZDA. Furthermore, the compressive strength of ZDA-modified PC with 0.5% moisture was even higher than that of the control without moisture. Similarly, CDA offered the possibility of improving the resistance to moisture. For example, an increase of 11.7% in the compressive strength over the control was obtained because of the introduction of 5.0% CDA when the moisture concentration of the sand was 0.5%. However, ZMA did not influence the moisture resistance positively. The compressive strength decreased because of its addition to PC in comparison with that of the control. In summary, the strength increased with the time, especially for the batches incorporating ZDA and ZMA.

Flexural strength versus the moisture

Figure 2 shows the influence of the moisture of the sand on the flexural strength of MMA-based PC with or without metallic monomers. The flexural strength for both batches, with and without metallic monomers, decreased significantly as the moisture concentration increased. However, in comparison with the control, the batch with ZDA had a much higher flexural strength and exhibited excellent resistance to moisture. At a 0.5% moisture concentration and an age of 7 days, for example, an increase of 122% in the flexural strength over the control was obtained because of the introduction of 5.0% ZDA. Furthermore, the flexural strength of ZDA-modified PC with 0.5% moisture was much

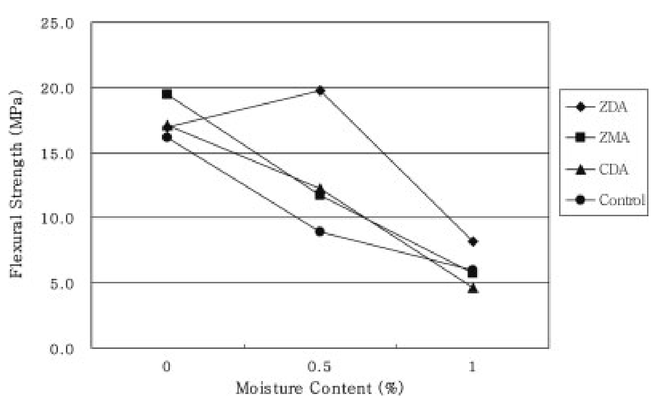

Figure 2 Flexural strength versus the moisture for MMA PC with 5.0 wt % metallic monomer.

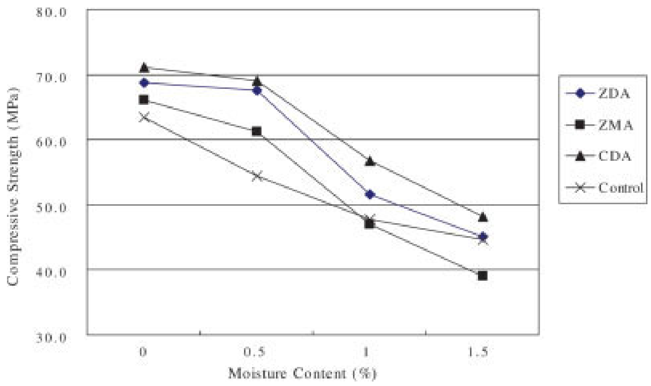

Figure 3 Compressive strength versus the moisture for polyester PC with 5.0 wt % metallic monomer. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

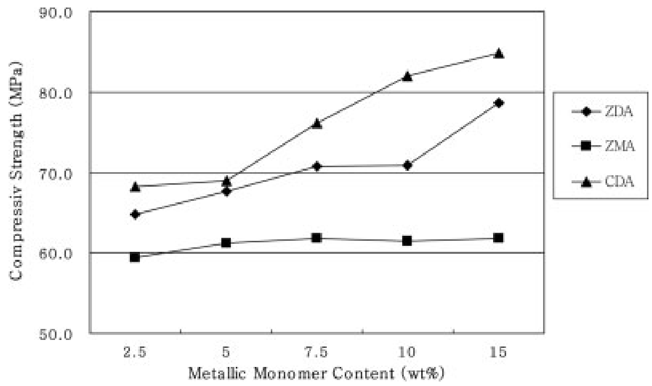

Figure 4 Compressive strength versus the metallic monomer concentration for polyester PC with 0.5% moisture.

higher than that of the control without moisture. The significant improvement in the resistance to the moisture of sand will possibly allow the use of wet aggregates in PC. Similarly, CDA offers the possibility of improving resistance to moisture in MMA-based PC systems. For example, an increase of 38% in the flexural strength over the control was obtained because of the introduction of 5.0 wt % CDA when the moisture concentration of the sand was 0.5%. Unfortunately, CDA did not work very well when the moisture concentration of the sand was 1.0%. For ZMA-modified PC, although an increase of 31% in the flexural strength was obtained over that of the control, its use in MMA-based PC is not desirable because ZMA caused defects in the specimens. The improvement in the flexural strength was unpredictable. The flexural strength varied greatly for different specimens.

Polyester PC system

Compressive strength versus the moisture

Figure 3 shows the effect of the sand moisture on the compressive strength of polyester PC with or without metallic monomers. Although the compressive strength for specimens with or without metallic monomers decreased significantly as the moisture concentration increased, ZDA and CDA did have significant effects on the moisture resistance. In comparison with the control, the batches with ZDA or CDA had a much higher compressive strength and exhibited excellent resistance to moisture. At a 0.5% moisture level, for example, increases of 24 and 27% in the compressive strength over the control were obtained because of the introduction of ZDA and CDA, respectively. Furthermore, at a 0.5% moisture level, the batches with ZDA or CDA had even higher compressive strength than the control without moisture. However, although ZMA improved the strength of polyester PC with moisture, it did not work very well when the moisture level exceeded 1.0%, as shown in Figure 3. For example, the compressive strength of polyester PC with ZMA was lower than that of the control when the moisture level was 1.5% with respect to the sand.

Figure 4 further shows the effects of the metallic monomers on the compressive strength of polyester PC at a 0.5% sand moisture level. The compressive strength of polyester PC increased with increasing levels of the metallic monomers, except for ZMA. This finding is in agreement with Figure 3, which indicates that when the moisture concentration was 0.5% with respect to the sand, the polyester PC incorporating ZDA and CDA suffered very little or no decrease in the compressive strength. In other words, the addition of ZDA and CDA to polyester PC made the compressive strength of polyester PC less dependent on moisture in comparison with the control.

Flexural strength versus the moisture

The flexural strength of polyester PC significantly benefited from the addition of metallic monomers, as shown in Figure 5. Although the flexural strength for

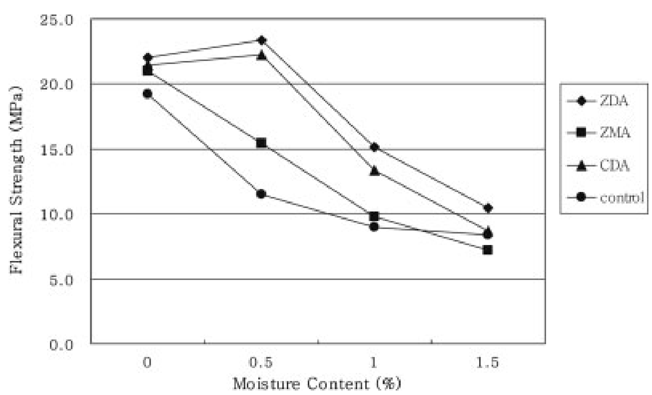

Figure 5 Flexural strength versus the moisture for polyester PC with 5.0 wt % metallic monomer.

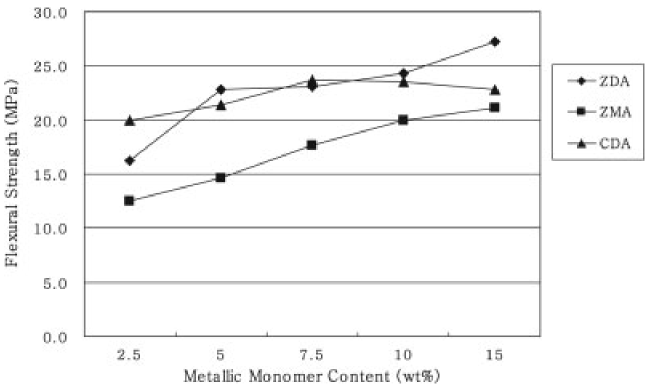

Figure 6 Flexural strength versus the metallic monomer concentration for polyester PC with 0.5% moisture.

the specimens with or without metallic monomers decreased significantly as the moisture concentration increased, ZDA and CDA did have a significant effect on the flexural strength. In comparison with the control, the PC with ZDA or CDA had a much higher flexural strength and exhibited excellent resistance to moisture. At a 0.5% moisture level, for instance, increases of 104 and 95% in the flexural strength over the control were obtained because of the introduction of ZDA and CDA, respectively. Furthermore, at a 0.5% moisture level, the batches with ZDA or CDA had even higher flexural strength than the control without moisture. However, ZMA did not work very well because the strength of PC with ZMA dropped faster than that of the control when the moisture level exceeded 1.0%, as shown in Figure 5. For example, the flexural strength of polyester PC with ZMA was lower than that of the control when the moisture concentration was 1.5% with respect to the sand.

Figure 6 further shows the effect of increasing levels of the metallic monomers on the flexural strength of polyester PC at a 0.5% moisture level. The flexural strength of polyester PC increased with increasing levels of the metallic monomers, except that they behaved differently. This finding is in agreement with Figure 5, which indicates that when the moisture concentration was 0.5% with respect to the sand, the polyester PC incorporating the metallic monomer suffered less or no decrease in the flexural strength in comparison with the control. In other words, the addition of metallic monomers to polyester PC made the flexural strength of polyester PC less dependent on the moisture in comparison with the control. ZDA and CDA performed better than ZMA for resistance to moisture.

CONCLUSIONS

On the basis of the test results, the following conclusions can be made.

1. The resistance to moisture was improved very significantly with the addition of ZDA and CDA. At a 0.5% moisture level and with the addition of 5.0% of ZDA, increases of 122% in the flexural strength and 50% in the compressive strength over the control were obtained for the MMA-based PC system. Increases of 104% in the flexural strength and 24% in the compressive strength over the control were obtained for the polyester PC system. At a 0.5% moisture level and with the addition of 5.0% CDA, increases of 38% in the flexural strength and 11.7% in the compressive strength over the control were obtained for the MMA-based PC system. Increases of 95% in the flexural strength and 27% in the compressive strength over the control were obtained for the polyester PC system. The remarkable increase in the strength indicates that ZDA and CDA may permit the possibility of using wet aggregates in PC construction.
2. ZDA and ZMA may have delayed the strength gain of MMA-based and polyester PCs, and a postthermal cure after a 24-h room-temperature cure may be necessary to achieve early strength.

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