Construction and Building Materials 127 (2016) 539–545

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Optimal mix and freeze-thaw durability of polysulfide polymer concrete

Sungnam Hong [a], Hyeonjun Kim [b], Sun-Kyu Park [c,*]

[a] College of Engineering, Sungkyunkwan University, Suwon 440-746, South Korea
[b] Samsung C&T Corporation, Seoul 137-956, South Korea
[c] School of Civil and Architectural Engineering, Sungkyunkwan University, Suwon 440-746, South Korea

HIGHLIGHTS

- Polysulfide polymer concrete mix design and freeze–thaw durability were examined.
- The optimal mix design was determined from two-stage binder tests and mixing tests.
- Specimen strengths for the optimal mix were compared with design code requirements.
- Strength and modulus losses after accelerated freeze–thaw cycling were measured.

ARTICLE INFO

Article history:
Received 19 May 2015
Received in revised form 27 September 2016
Accepted 6 October 2016

Keywords:
Polysulfide
Polymer concrete
Freeze–thaw
Mechanical properties
Optimal mix

ABSTRACT

A study was conducted to determine the optimal mix design for polysulfide polymer concrete (PPC). Two-stage binder tests and polymer concrete mixing tests were carried out for this purpose. The optimal mixing ratio was determined from the test results. In addition, the strength and freeze–thaw resistance of specimens produced using the optimal mixing ratio were evaluated. The results of the strength tests showed that the specimens satisfied the strength requirements of the relevant design codes. Repeated freezing and thawing significantly decreased the mechanical strength of the specimens but had an insignificant effect on the specimens' relative dynamic modulus of elasticity (RDME). It was found that more than 300 freeze–thaw cycles could cause a problem for PPC in terms of its strength.

1. Introduction

Improvements in the performance of construction materials and advancements in construction technology [1–2] have contributed to growth in public infrastructure. The structural demands on ultra-large bridges and the harsh environments to which they are exposed have prompted industry-wide efforts to reduce the self-weight of ultra-large bridges and improve their strength and durability [3]. There is therefore growing interest in new materials that could replace asphalt concrete and Portland cement concrete, which have historically been favored as pavement materials.

A series of studies dating back to the 1950s have evaluated the feasibility of using polymer concrete as a pavement material [4–8]. Based on the results of these studies, the American Concrete Institute (ACI) and the American Association of State Highway and Transportation Officials (AASHTO) established a number of guidelines for polymer concrete use, including the *Guide for Polymer Concrete Overlays* and the *Guide Specifications for Polymer Concrete Bridge Deck Overlays* [9–10]. These publications provide comprehensive design and construction guidelines for the use of polymer concrete as a pavement material for bridges and other structures. However, there have been studies on concrete produced using polysulfide polymer or epoxy resin (referred to hereinafter as polysulfide polymer concrete, or PPC) [11–15]. Furthermore, no studies have been conducted on how to determine the optimal mix design for PPC, despite the fact that such findings are essential if PPC is to be employed in structures. The freeze–thaw durability of PPC should also be assessed before it is used as a pavement material for bridges.

This study was conducted to attempt to determine the optimal mix design for PPC. Laboratory tests were first performed to establish the optimal formulation for the binder, which is composed of a polysulfide polymer, an epoxy resin, a hardener, and a catalyst. The optimal mix design for PPC was then determined from a series of laboratory tests. The strength and freeze–thaw durability of PPC specimens developed using the optimal mix design were then tested.

* Corresponding author.
E-mail address: skpark@skku.edu (S.-K. Park).

http://dx.doi.org/10.1016/j.conbuildmat.2016.10.056
0950-0618/

2. Experimental program

2.1. Materials

PPC is typically composed of a binder, a catalyst, and coarse and fine aggregates. The binder used in this study consisted of a polysulfide polymer, an epoxy resin, a hardener, and a catalyst. For this study, YD-128, a bisphenol A epoxy resin (Kukdo Chemical, Seoul, South Korea), and LP-3, a polysulfide liquid polymer (SPI Chem, Philadelphia, PA, USA), were used as the main materials. JEFFAMINE D-230, an amine hardener manufactured by Huntsman International LLC (Salt Lake City, UT, USA), and HIESCAT HI-54K, a metal salt catalyst manufactured by Keumjung Co., Ltd. (Ulsan, South Korea), were used as the hardener and catalyst, respectively. Information on the physical properties of the epoxy resin, polymer, hardener, and catalyst provided by the manufacturers is shown in Table 1.

Silica sand with an average diameter in the range of 0.35–0.7 mm was selected for use as the coarse aggregate. To ensure excellent workability of the aggregate, silica powder was used as the fine aggregate. The powder was made by grinding the silica sand used as the coarse aggregate and filtering it with a No. 230 (63-μ) sieve. The physical properties and chemical composition of the silica aggregates are listed in Table 2.

2.2. Mixing tests

2.2.1. Binder

It was reported in a previous study that the optimal binding result was obtained when the primary materials (bisphenol A epoxy resin and polysulfide liquid polymer) were mixed at a ratio of 6:4 [14]. Accordingly, the primary binding materials used in this study were mixed at this same ratio.

Over the two stages of this study, a series of lab tests was performed to establish the formulation of the binder. In the first stage, the variations in the tensile strength, tensile elongation, and gel time of the binder were observed with respect to the proportion of the hardener, which ranged from 3% to 43% relative to the weight of the primary materials. Based on the results, the appropriate range for the optimal mixture ratio for the hardener, relative to the weight of the primary materials, was determined. In the second stage, the effectiveness of the catalyst was examined for each optimal mixture ratio determined in the first-stage tests. The ratio of catalyst content to the primary materials content varied from 1 to 3% by weight, and the optimal binder ratio was determined from a series of results obtained at each mixture rate. Finally, the optimal binder ratio was confirmed by verifying that the test results for the binder specimens for each mixture ratio satisfied the recommendations of ACI 548.9-08 [16]. The binder specimens were produced and tested in accordance with ASTM standard test methods [17,18].

2.2.2. Polymer concrete

The recommended ratio of binder to aggregate (coarse + filler) for polymer concrete is typically 1:3.7 [8]. However, it was reported in a previous study that problems could occur with the mixing properties and liquidity of polymer concrete if PPC was produced with this mixture ratio. It was also reported that the overall performance of PPC could be improved if the ratio of coarse aggregate to filler aggregate was maintained at a rate of 7:3 by weight [15]. Therefore, in this study, the mixture ratio between the coarse and filler aggregates was maintained at 7:3. The container residue (the runoff amount), the 10-min flow, and the thickness after hardening were each measured for binder-to-aggregate ratios of 1:2.0–1:3.7 by weight.

The flow and thickness of each mixture were measured in accordance with ASTM C1362 [19] and ASTM D35649 [20]. However, a standard method for assessing concrete mixture properties has yet to be established. Therefore, the properties of the PPC mixtures prepared in this study were assessed in accordance with KS M5000 [21], which includes some approximate test methods require that 700 g of a PPC specimen be poured into a container of a specific size and that the PPC's mixture properties be evaluated by measuring the residual amount in the container when the PPC specimen flows out of the container.

2.3. Mechanical and durability tests

2.3.1. Strength tests

Strength tests were carried out to evaluate the performance of the PPC specimens prepared based on the optimal ratio determined from the results of the mixing tests. Compressive strength tests were performed in accordance with ASTM C579 Test Method B [22]. Several cubic specimens $50 \times 50 \times 50$ mm in size (height × width × length) were produced at room temperature for use in the compressive strength testing. For comparison with the compressive strengths of polymer concrete at 3- and 24-h material ages, as recommended by ACI 548.9-08 [16], the specimens were cured at 23 °C for 3 and 24 h, respectively, before being subjected to compressive strength testing. Flexural strength testing was performed using prismatic beam samples $25 \times 25 \times 300$ mm in size, in accordance with ASTM C580 Test Method A [23]. The prismatic beam samples were cured at 23 °C for seven days, and the results of the flexural strength tests were compared with the epoxy polymer concrete flexural strength value recommended by ACI 548.5-98 [9]. Various methods can be used to measure the bond strength. In this study, the bond strength was measured using the direct pull-off method, for which the specimen production and measurement procedure are easy. The cylindrical

Table 1
Physical properties of the resin, polymer, hardener, and catalyst.

YD-128 (Bisphenol A epoxy resin)	Epoxy equivalent weight (g/eq) 184–190	Viscosity (25 °C, mPa·s) 11,500–13,500	Hy-Cl (%, max) 0.05	Specific gravity (20 °C) 1.17	
LP-3 (Polysulfide liquid polymer)	Molecular weight (g/mol) 1000	Viscosity (25 °C, mPa·s) 940–1440	Moisture (%, max) 0.1	Specific gravity (20 °C) 1.29	Mercaptan content (%) 5.9–7.7
JEFFAMINE D-230 (Amine hardener)	Molecular weight (g/mol) 230	Viscosity (25 °C, mPa·s) 9	Specific gravity (20 °C) 0.948	Density (20 °C, kg/m^3) 946.7	
HIESCAT HI-54 K (Epoxy catalyst)	Specific gravity (20 °C) 0.97–0.99	Amine value (KOH mg/g) 610–630	Viscosity (25 °C, mPa·s) 150–250	Water content (%) <0.5	