Construction and Building Materials 167 (2018) 185–196

Contents lists available at ScienceDirect

Construction and Building Materials

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

Optimizing the mixture design of polymer concrete: An experimental investigation

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HIGHLIGHTS

- Polymer concrete (PC) mixes were studies using destructive and non-destructive testing methods.
- The optimum mix design of PC was determined using Taguchi and ANOVA methods.
- The temperature during testing was found to be the most influential parameter affecting the destructive test results.
- Predictive models were proposed to determine the splitting tensile and flexural strengths of PC.

ARTICLE INFO

Article history:
Received 2 September 2017
Received in revised form 9 December 2017
Accepted 31 January 2018

Keywords:
Polymer concrete (PC)
Destructive tests
Non-destructive test (NDT)
Mechanical behavior
Taguchi method
Analysis of variance (ANOVA)

ABSTRACT

Over the last few decades, polymer concrete (PC) has been finding use in quick repairing of concrete structures. However, there have been only few studies on the mechanical behavior of PC. The aim of this study is to evaluate the mechanical behavior of PC using destructive and non-destructive tests (NDT). The mixtures were prepared with three different polymer ratios (10%, 12%, and 14%) and two different coarse aggregate sizes (4.75–9.5 mm and 9.5–19 mm). The samples were subsequently tested under three different temperatures (−15 °C, +25 °C, and +65 °C). The Taguchi method and analysis of variance (ANOVA) were used to optimize PC mixes based on the compressive, splitting-tensile, and flexural strengths under varying polymer content, coarse aggregate size, and temperature. NDTs, including ultrasonic pulse velocity and electrical resistivity tests, were carried out to gain insights into the porosity and void content of the specimens. Scanning electron microscopy (SEM) was used to analyze the bonding interface between aggregates and polymer, microstructure phase, and pores that were present in the structure of the PC. Results show that a decrease in the temperature from +25 °C to −15 °C led to an improvement in the mechanical properties of PC mixes, whereas an increase in the temperature from +25 °C to +65 °C adversely affected the mechanical properties. Based on NDT, it was found that increasing the coarse aggregate size and polymer ratio reduced the porosity of specimens. This is attributed to the decreased surface area to volume ratio with increasing particle size, which allowed the polymer to completely coat the surface of aggregates. Finally, a set of expressions was proposed to predict the mechanical properties of PC.

1. Introduction

Evolution of the civil engineering discipline has led to an increased demand for engineering materials possessing high compressive, tensile, and flexural strengths and excellent durability and resistance to environmental effects. Concrete is the most widely used material in construction applications worldwide. The development of modern civil engineering construction has generated a strong demand to modify concrete properties and produce new types of concretes.

Polymer was introduced for use in repair and rehabilitation of structures [1]. Polymer concrete (PC) is prepared by mixing a polymeric resin with an aggregate mixture [2]. The most commonly used resins for PC are unsaturated polyester resin, epoxy resin, furan resin, polyurethane resin, and urea formaldehyde resin [3]. The only component that increases the cost of PC is the resin; therefore, attempts have been made to determine the optimum

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https://doi.org/10.1016/j.conbuildmat.2018.01.191
0950-0618/© 2018 Published by Elsevier Ltd.

resin content to achieve acceptable properties at low costs. The advantages of PC compared to cement concrete are its high compressive, flexural and tensile strengths, fast curing, low permeability, and improved protection against corrosion [4–6]. Therefore, PC is widely used as a repair material in infrastructures such as concrete structures and pavements, and it is used in machinery foundations in laboratories, factories, and building cladding [7,8]. Furthermore, PC has higher vibration damping characteristics than cement concrete [9–10].

Several studies have been conducted to test polymer properties. Vipulanandan and Mantrala [11] evaluated the properties of polyester PC including the modulus of elasticity, Poisson's ratio, and compressive strength. They indicated that by adding 6% of glass fiber by weight to the mixture, the compressive strength increased by up to 16%. Agavriloaie et al. [12] studied the mechanical properties of epoxy polyurethane acryl and aggregates, including compressive strength, flexural strength, and elasticity modulus. They reported that the compressive and flexural tests and modulus of elasticity results were 52.5 MPa, 11.5 MPa, and 2.4 GPa, respectively.

It is understood that there are many parameters such as the aggregate gradation, paste content, and additives that affect the mixture performance. Shokrieh et al. [13] investigated the effects of aggregate size, epoxy resin weight percentage, and chopped glass fiber percentage on the compressive strength, bending strengths and interfacial shear strength between the PC and steel. It was reported that among all factors the polymer content had the most significant effect on the properties of PC. The mechanical properties of PC containing electronic plastic waste were studied by Bulut and Sahin [14]. The study showed that the increase in the ratio of resin increased the compressive strength while not affecting the splitting-tensile and flexural strengths in any significant way. Additionally, they concluded that the ideal resin ratio and electronic plastic ratio are 15% and 5%, respectively.

Although a relatively large number of investigations have been conducted to develop promising applications of polymer concrete in the last few decades, there have been very few studies on optimizing the mechanical behavior of polymer concrete. Three key parameters affect the characteristics of PC, namely the aggregate properties, epoxy resin content, and the temperature of the surrounding environment.

Accordingly, in this investigation, to study the effect of the polymer–cement ratio on the mechanical properties of PC, three different epoxy resin ratios (10, 12, and 14%) were prepared. It was previously shown that, when long-term and short-term concrete behavior is considered, the optimized strength is established around a polymer–cement ratio of 10–15% [15–17]. Two different coarse aggregate sizes were studied to evaluate the effect of the aggregate properties. Additionally, the PC is susceptible to changes in temperatures due to the synthetic viscoelastic resin binder used in its production. Thus, specimens were tested under three different temperatures (i.e. −15 °C, +25 °C, and +65 °C) in destructive tests to investigate the influence of this important parameter. The Taguchi method and analysis of variance (ANOVA) were used to establish the influence of each studied test parameter. Nondestructive tests (NDT) were also carried out to evaluate the quality, integrity, and durability, and determine the dynamic elastic modulus of specimens. In total, over 170 specimens were tested to investigate all of these parameters.

2. Materials and specimen preparation

The properties of PC are influenced by the content of epoxy resin, aggregate type and size distribution, and curing conditions. The components and preparation of PC specimens used in this study were as follows:

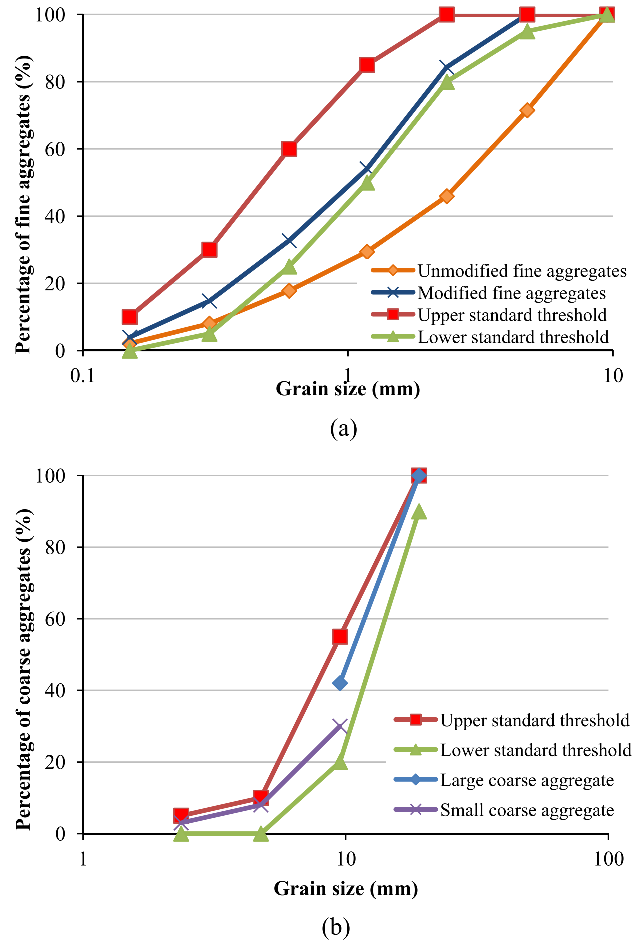

Fig. 1. The aggregate size distribution of (a) fine aggregate, (b) coarse aggregate.

2.1. Aggregates

Generally, more than 80% of the volume of PC is composed of aggregates. Therefore, the quality of aggregates influences the mechanical properties of PC. Fig. 1a and b depict the grading curve of fine and coarse aggregates with respect to ASTM C33 [18]. Two types of coarse aggregates were used with 4.75–9.5 mm and 9.5–19 mm grain size. The coarse aggregates were used from natural crushed limestone with the maximum dimension of 19 mm. Natural river sand, with the nominal maximum size of 4.75 mm, was used as the fine aggregate.. The different percentages of coarse and fine aggregates were mixed to determine the optimum mix ratio according to ASTM C29 [19]. The optimum mix ratio of the coarse to fine aggregates was found to be equal to 1:1 for both types of coarse aggregates.

2.2. Polymer

The epoxy resin used in this study was called NITOBOND-EP and had a base/hardener mix ratio of 1.73:1 by weight [20]. According to manufacturer guidelines, this polymer had a compressive and tensile strength of 70 MPa and 36 MPa, respectively, after a curing time of 5 days at 35 °C.

2.3. Preparation of specimens

Cylinder specimens with the size of 76 × 152 mm and 76 × 60 mm (diameter × height) were prepared for the uniaxial compression and splitting-tensile tests, respectively. The prismatic