Construction and Building Materials 112 (2016) 183–190

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental study and constitutive modeling of polymer concrete's behavior in compression

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HIGHLIGHTS

- Investigating the effect of epoxy resin content on the behavior of polymer concrete.
- Comparison of the behavior of polymer concrete and ordinary concrete.
- Use of the disturbed state concept in modeling the compressive behavior of polymer concrete.

ARTICLE INFO

Article history:
Received 4 October 2015
Received in revised form 12 January 2016
Accepted 19 February 2016

Keywords:
Polymer concrete
Epoxy resin
Constitutive modeling
DSC model
Stress–strain curve

ABSTRACT

In this research, compressive and tensile behaviors of polymer concrete have been investigated. A series of tests were performed on polymer concrete (PC) specimens with different amounts of epoxy resin to investigate the effect of epoxy resin content on behavior of PC. For prediction of this behavior the disturbed state concept (DSC) has been used. The proposed model was then verified by predicting laboratory compressive tests used to find parameters along with independent data sets from other researchers. Moreover, the applicability of existing cement concrete models for predicting the behavior of PC was assessed since they are basically phenomenological, based on experimental observation of the cement concrete testing. Finally, the DSC was compared with other existing models and it was concluded that it has highest accuracy among others.

1. Introduction

Regarding many desirable properties of cement concrete, it is one of the most popular materials in Civil Engineering. However, it also has deficiencies such as low tensile and flexural strengths, poor durability, high porosity, and vulnerability to acidic environments [1]. Steinberg et al. [2] proposed an approach to enhance the properties of cement concrete by replacing water–cement content with epoxy resin which led to a new composite material called 'polymer concrete'.

Since then, several research works have been reported on the properties and applications of polymer concrete [3–8]. It was seen that PC has relatively low cure shrinkage; good chemical resistance; high durability, strength and strain; resistance against corrosion; and excellent adhesion characteristics to most surfaces.

Low cure shrinkage and excellent adhesion to conventional concrete is a desirable attribute in repair materials [9–12]. Its mechanical strength, chemical resistance and durability reduce the need for maintenance and frequent repairs required by conventional concrete [5]; thereby, it can be used for early reopening of a runway [4] as well as in acid tanks. Further, having these qualities together, PC is recommended for applications such as hydraulic structures and geothermal energy process [13].

The favorable properties of PC have led to its growing commercial applications in recent years. For instance, in 2002 PC was used for lining the sewer pipes in Offenbach, Germany; a few years later, the Upper Northwest Interceptor in Sacramento County was bid with PC [14]; it was also used in overlays by several states including California and Nevada [15]; it was used in 2011 in repairing the columns of Highway 450 & 90 Overpass, Hopkinton, Massachusetts, USA, as well as for the repairs of the University of Arizona condensate return tank slab, Tucson, Arizona, USA.

In order to have a rational and cost-effective design for existing applications of PC and to take full advantage of the material, an understanding of the complete stress–strain curve is essential.

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http://dx.doi.org/10.1016/j.conbuildmat.2016.02.100
0950-0618/

Many researchers have studied the stress–strain behavior of conventional concretes under compressive loading. However, none of them were generally extended to predict the behavior of PC. A valuable review on stress–strain models for cement concrete is presented by Lim and Ozbakkaloglu [16].

The cement concrete models are based on experimental observation of the cement concrete testing and basically phenomenological. Moreover, the applicability of them are often restricted to specific specimen subsets and cannot be necessarily used for new materials. Therefore, in this study their applicability for predicting the behavior of PC was assessed and a relatively new approach to the behavior of materials, the disturbed state concept (DSC), was used to predict the behavior of PC. For this purpose, a series of compressive and tensile tests were conducted on PC specimens with different amounts of epoxy resin to obtain parameters as well as to investigate the effect of epoxy resin content on the behavior of PC. The DSC was then verified by predicting laboratory compressive tests used to find parameters along with independent data sets from other researchers. Finally, it was quantitatively compared with some of existing models. One of the advantages of the DSC is that it has physical explanation of the behavior of material whilst most of foregoing models are mathematical and simply based on measured conventional concrete. Thus, most of them cannot be used for two- and three- dimensional simulations.

2. Materials

2.1. Polymer

In this study, the epoxy resin was used as polymer. The epoxy mixture consisted of two parts: the resin (base) referred to as part "A" (bisphenol A based), and the hardener referred to as part "B" (polyamide). Three kinds of epoxy resins from different companies were used: NITOBOND-EP (with resin/hardener mix ratio of 1.9:1.1), ML506-HA32 (with mix ratio of 2:1), and PR700-PH500 (with mix ratio of 2:1). Based on conducted compressive tests of epoxies, epoxy resin with the highest compressive strength was selected for the subsequent stages of this study.

2.2. Aggregates

Aggregates are the most important part of PC as they constitute major part of its total volume and vastly influence its behavior. The size gradation of aggregates should provide the lowest possible void volume (maximum dry bulk density) [17]. In this study, two types of aggregates (fine and coarse aggregates) were used to prepare polymer concrete specimens. The size of fine aggregate ranged between 0 and 4.75 mm (0.18 in) while the size of coarse aggregates varied from 4.75 to 19 mm (0.18–0.74 in).

3. Experimental investigation

The experimental procedure of this study included four main stages in order to determine and present: (1) The compressive strength of different types of epoxy resins, (2) The mix ratio of fine and coarse aggregates corresponding to the maximum dry bulk density, (3) The variation of compressive and tensile strengths of PC with different epoxy resin contents, and (4) The complete stress–strain curves of PC with different epoxy resin contents in compression.

3.1. Epoxy resins preparation and compressive test

In order to determine the compressive strength of epoxy resin specimens, three type of epoxy resins were tested according to ASTM D695 [18]. Epoxy resin specimens of cylindrical shape with diameter (D) of 27.4 mm (1.07 in) and length (L) of 57.6 mm (2.26 in) were casted. Each type of epoxy resin was mixed by a mixing paddle for two minutes to have a fairly uniform color. All specimens were then vibrated on vibration table to ensure good compaction. To provide easier de-molding of the PC specimens, the inner surfaces of molds were lubricated with oil before casting. The prepared epoxy resin specimens were cured for seven days at room temperature. Three specimens of each epoxy resin type were made and tested.

3.2. The optimum aggregate ratio for maximum dry bulk density

Different amounts of fine and coarse aggregates were mixed together to obtain the maximum dry bulk density according to ASTM C29 [19]. The weight of coarse aggregate was kept constant while the weight of fine aggregate was increased at ten percent increments. For example, at first step, coarse aggregate with 70% (22.4 kg (49.4 lbs)) of total weight and fine aggregate with 30% (9.6 kg (21.2 lbs)) of total weight were mixed together. Then, the mixture was poured in a (0.014 m^3 (0.5 ft^3)) steel cylindrical bucket in three layers, and each layer was rodded 25 times until the bucket became full. Afterwards, the mixture was weighted and its density was calculated. The mixture was then poured back into a larger bucket and 10% (5.3 kg (11.7 lbs)) more fine aggregate was added. Then, the mixture was mixed, and a new mixture of 60% (22.4 kg (49.4 lbs)) coarse aggregate and 40% (14.9 kg (32.8 lbs)) fine aggregate was obtained. This process was continued until a mixture of 30% (22.4 kg (49.4 lbs)) coarse aggregate and 70% (52.3 kg (115.3 lbs)) fine aggregate was obtained.

3.3. Polymer concrete preparation

In order to investigate the effect of epoxy resin content on the behavior of PC, three different mixtures were prepared. For each of which, a different percentage of epoxy resin was added. The epoxy resin percentages were 10%, 12%, and 14% of the total weight of mixture. The percentages of epoxy resin in this study were consistent with the range cited in literature [20–22]. However, there is no specific mix design for polymer concrete established to achieve targeted properties and performance [20].

To prepare PC, part A and B of epoxy resin were mixed by a mixing paddle for three minutes. The epoxy resin and aggregates were mixed together at abovementioned percentages with electrical drill for another three minutes. The mixtures were then casted into cylindrical plastic molds with dimensions of D = 86.5 mm (3.4 in) and L = 173 mm (6.8 in). Note, the inner surfaces of the molds were covered with release film and lubricated for better extraction of specimens. The specimens were cured at room temperature for seven days. Both ends of PC specimens were capped with high-strength gypsum plaster according to ASTM C617 [23] to be prepared for compressive testing in accordance with ASTM C39 [24]. Specimens were weighted and dimensions were measured prior to testing. Specimens at different stages are shown in Fig. 1. In all specimens, the failure in shear mode was observed (Fig. 2a).

On the other hand, nine cylindrical specimens with diameter of 86.5 mm (3.4 in) were prepared for Brazilian tests [25]. The method of sample preparation was similar to that of compressive samples. Three sets of specimens with different percentages of epoxy resin (10%, 12%, and 14% of the total weight of mixture) were prepared and tested. Splitting tensile strength (T) of each specimen was calculated as follows:

$$T = \frac{2P}{Ld\pi} \quad (1)$$

where P = maximum applied load; L = length of specimen; and d = diameter of specimen. A typical fracture trajectory of tensile specimens is shown in Fig. 2(b).

3.4. Experimental results

The compressive tests results of epoxy resins are shown in Table 1. It can be seen that ML506-HA32 and PR700-PH500 resins