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Flexural fatigue behavior of polymer-modified pervious concrete with single sized aggregates

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HIGHLIGHTS

- The probabilistic distribution of equivalent fatigue life for PPC was proposed.
- The coefficients of fatigue equation have been determined for PPC.
- The fatigue life in descending order is PPC-27.5, PPC-32.5, and PPC-37.5.

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ABSTRACT

The objective of this research is to evaluate the flexural fatigue behavior of polymer-modified pervious concrete (PPC) with single sized aggregates which could be used in base course of infrastructures. Three aggregate sizes (27.5 mm, 32.5 mm, and 37.5 mm) were selected for single sized aggregate mixtures. A laboratory testing program was conducted obtaining the fatigue lives of PPC at various stress levels and stress ratios. 65 beam specimens of 150 mm × 150 mm × 550 mm totally were produced for each mix type, ten of which were adopted to determine the static flexural strength of PPC prior to fatigue testing. To incorporate the effects of stress level *S*, stress ratio *R* and survival probability, equivalent fatigue-life was employed to study the fatigue equation of PPC. The studies indicate that statistical distribution of equivalent fatigue life of PPC approximately followed the two-parameter Weibull distribution. The *S-N* relation curves and regression equations corresponding to different survival probabilities (0.5–0.95) were obtained by regression analysis. Based on these results, the fatigue life ranking as PPC-27.5 > PPC-32.5 > PPC-37.5 was declared.

1. Introduction

Pervious concrete consists with coarse aggregate, cement, water, little to no fines and admixtures. It is proportioned by gap grading the coarse aggregates as such to create high level of porosities (15–35%) and networking of interconnected pores in the concrete, which differs from conventional concrete [1]. Because of its pervious characteristics, the pervious concrete was always paved in the surface course or/and base course to reduce the surface runoff water, improve the water quality, and enhance the pavement skid resistance by rapid drainage of water during storm events, as well,to lower the on-site noise level [2–6].

Generally, the pervious concrete with excellent water permeability will result in poor mechanical behavior [7,8]. In order to obtain required continuous voids and sufficient strength, Huang and Kevern evaluated the performance of polymer modified pervious concrete and found that the incorporation of fibers increased the void content, permeability, and compressive strength. And more significantly, improve the splitting tensile strength [9,10]. In addition, the influence of aggregate type, aggregate size, aggregate grading and cement paste characteristic on porosity, compressive strength and flexural strength of pervious concrete was evaluated, respectively [11–15].

Nevertheless, a majority of previous studies were focused on hydraulic characteristics and creating the optimum balance between strength and permeability of pervious concrete [16–18]. In recent literatures, limited studies were reported with respect to the flexural fatigue behavior of pervious concrete. Actually, the

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fatigue behavior of pervious concrete is an important design parameter for surface courses or base courses, which have to be subjected to repetitive fatigue load. Chen et al. obtained the fatigue life of pervious concrete for the surface course with continuous grading by the flexural fatigue test [19]. It was found that polymer-modified pervious concrete (PPC) had by far longer flexural fatigue life than SCM-modified pervious concrete at all stress levels, since the polymer helped to reduce cracking or to delay the crack development. However, the flexural fatigue behavior of PPC which was used for the base course has not been studied. Previous study indicates that permeable base of pervious concrete, with high porosity for drain off water from pavement structure, could efficiently reduce the pavement early damage and prolong the road service life [20,21]. It is of great interest for both researchers and engineers to investigate the fatigue behavior of pervious concrete for the permeable base.

The primary goal of this study is to investigate the flexural fatigue behavior of polymer-modified pervious concrete (PPC) as permeable bases. The effective porosity and static flexural strength of PPC were detected prior to fatigue test. A laboratory testing program was applied to collect the fatigue lives of PPC at various stress levels and ratios. To incorporate the effects of stress level S, stress ratio R and survival probability, equivalent fatigue-life was employed to study the fatigue equation of PPC. The fatigue prediction models for the PPC with single sized aggregates were proposed and the flexural fatigue behavior of PPC-27.5, PPC-32.5 and PPC-37.5 was compared.

2. Experiment program and testing methods

The first step in performing this research was to select the aggregate sizes and proportion PPC mixtures using single sized aggregates so that the required connected porosity was achieved. Subsequently, the effective porosity, static flexural test and flexural fatigue test were determined. The methodology adopted for each steps above will be detailed in the following subsections.

2.1. Concrete mixture proportions

The pervious concrete for permeable base includes two aggregate types: grading and single sized. Li et al. investigated the mechanical characteristics of grading and single sized pervious concrete by the mechanical simulate, respectively [22]. The results indicated that the single sized aggregates weakened the stress concentrating between cement paste and aggregates. The stress concentrating of single sized pervious concrete was transferred to aggregates. In this study, the single sized pervious concrete was chosen to investigate the flexural fatigue behavior of pervious concrete.

The pervious concrete mixtures in this investigation were consisted of cement, single sized limestone aggregate, water, superplasticizer, and polymer. The mix proportions of PPC used for the study are stated in Table 1. The water-to-cement ratio (w/c) and cement-to-aggregate ratio for all mixtures were maintained constant at 0.32 and 1:6, respectively.

The cement was ordinary Portland cement (type P.O. 42.5, China). The actual technical index of cement is stated in Table 2.

Three aggregate sizes (27.5 mm, 32.5 mm, and 37.5 mm) were selected for single sized aggregate mixtures used in pervious concrete. It should be noted that the median of diameters was defined as the size of aggregate. For instance, the diameter of aggregate ranging from 25 to 30 mm was named as 27.5 mm while the corresponding PPC was named PPC-27.5. As a result, three pervious concretes with single size between 25 mm and 30 mm, 30 mm and 35 mm, and 35 mm and 40 mm were achieved, and named as PPC-27.5, PPC-32.5, and PPC-37.5, respectively. The actual technical indexes of aggregate are stated in Table 3. It has been proved that the permeability and strength of the single sized pervious concrete in present study met the requirement of the permeable base [22].

To improve the property of PPC, a polymer which is a mixture of acrylic and polycarboxylic emulsion, was added to the mixture at 10% by weight of water. The polymer was produced by a company of Hebei province in China as shown in Fig. 1. The main properties of modifier are listed in Table 4. In addition, a polycarboxylate based superplasticizer was added to mixtures to adjust the workability of the fresh mixture.

2.2. Specimen preparation

In this study, test specimens had two sizes. A cube specimen 150 mm × 150 mm × 150 mm was used to measure the effective porosity. A beam specimen 150 mm × 150 mm × 550 mm was used to measure the static flexural and flexural fatigue. To improve the bond between aggregate and cement paste, the aggregate was first mixed with dry cement for 60 s, and then the aqueous colloidal solution contained modifier was added to mix for 60 s. Finally, the remaining water was added gradually in 90 s during the progress of mixing before casting. Specimens were placed by rodding 25 times from the edge to the center in three layers. The samples were demolded after 24 h, placed in a fog room at (20 ± 2) °C and 95% relative humidity, and cured according to Chinese Standard GB/T 50081-2002 [23].

Table 1
Mix proportion of PPC.

Mix type	Cement-to-aggregate ratio	w/c ratio	Aggregate (kg/cm^3)	Cement (kg/cm^3)	Water (kg/cm^3)	Polymer (kg/cm^3)
PPC-27.5	1:6	0.32	1657	276	88.40	8.84
PPC-32.5	1:6	0.32	1644	274	87.69	8.77
PPC-37.5	1:6	0.32	1632	272	87.04	8.70

Table 2
Actual technical index of cement.

Cement type	Density	Specific surface area	Setting time (min)		Compressive strength (MPa)		Flexural strength (MPa)	
	(g/cm^3)	(m^2/kg)	Initial set	Final set	3 d	28 d	3 d	28 d
P.O.42.5	2.96	355	149	237	26.6	50.7	5.2	9.3