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Flexural fatigue life analysis of unsaturated polyester-methyl methacrylate polymer concrete

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HIGHLIGHTS

- Laboratory evaluations were performed to examine the flexural fatigue behavior of UP-MMA polymer concrete.
- A two-parameter Weibull distribution was used to analyze the fatigue life probability distributions.
- The goodness-of-the-fit of the fatigue life data was verified by means of the Kolmogorov-Smirnov test.
- A single-log fatigue equation was derived to predict the fatigue life of UP-MMA polymer concrete.

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ABSTRACT

Laboratory and statistical evaluations were performed to examine the flexural fatigue performance of unsaturated polyester-methyl methacrylate (UP-MMA) polymer concrete. Target stress levels were 0.9, 0.8, 0.7, and 0.6 with a fixed stress ratio of 0.1. A 5 Hz sinusoidal load with a constant-amplitude frequency was applied to a prismatic specimen (100 × 100 × 400 mm) using a 250-kN universal testing machine (UTM). MMA contents considered were 0, 10, 20, and 30 wt.%. In addition, the two-parameter Weibull distribution was employed to analyze the fatigue life probability distributions of UP-MMA polymer concrete. Three different analysis methods—the graphical method, method of moment, and method of maximum likelihood estimation—were applied to estimate the distribution parameters of the two-parameter Weibull distribution. The results have shown that the two-parameter Weibull distribution describes the fatigue life probability distributions of UP-MMA polymer concrete with quite high statistical correlation coefficients. Also, the goodness-of-the-fit of the fatigue life data obtained was verified by means of the Kolmogorov-Smirnov test, which were all accepted at a 5% significance level. Finally, a single-log fatigue equation was derived to predict the fatigue life of UP-MMA polymer concrete.

1. Introduction

Polymer concrete is one of the concrete-polymer composites incorporating a 8–15 wt.% liquid resin as a binder. Polymer concrete was first developed in the 1950s and started to prevail since the 1970s [1,2]. Currently, polymer concrete is commonly used for manufacturing precast products (e.g., manholes, sewage pipes, and building walls) and repairing existing concrete pavements and bridge decks due to its inherent benefits such as short curing time, high mechanical and bond strengths, as well as strong chemical and freeze-thaw resistance over ordinary portland cement concrete. Polymer concrete also reportedly has some shortcomings arising from high price of resin, large setting shrinkage, temperature sensitivity, volatility, and flammability, and thus various research efforts are underway to mitigate such negative effects by improving binder characteristics and developing alternative resins and chemical admixtures [1–4].

One of the most widely used polymer concretes for repairing existing pavements and bridge decks is polymer concrete using unsaturated polyester (UP) resin binders. However, since the UP resin has a high viscosity at low temperatures, and thus may worsen the workability of mixtures, a methyl methacrylate (MMA) monomer is typically added to improve the workability and low-temperature mechanical strength. Yeon et al. [5] characterized the workability and strength development of UP polymer concrete incorporating 0–50 wt.% MMA monomer (hereinafter, “UP-MMA polymer concrete”) and proved that UP-MMA polymer concrete

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Notations

C_c	correlation coefficient
$E(N)$	mean value of the fatigue life
$f(n)$	probability density function
$F_a(X)$	cumulative histogram observed
f_a	fatigue stress amplitude
$F_e(X)$	cumulative distribution function assumed
f_m	mean fatigue stress
f_{max}	maximum fatigue stress
f_{min}	minimum fatigue stress
$F_N(n)$	cumulative distribution function
f_r	static flexural strength
L_R	survivorship function
N	number of load repetitions to failure (or fatigue life)
n	specific value of the random variable
n_0	location parameter (or the minimum life)
P_f	failure probability
R	stress ratio = f_{min}/f_{max}
S	stress level = f_{max}/f_r
u	scale parameter (or the characteristic life) of the Weibull distribution
α	shape parameter (or the Weibull slope) of the Weibull distribution
$\gamma(\cdot)$	gamma function

can be a good candidate for both precast and cast-in-place applications. Hyun and Yeon [6] investigated the mechanical properties of UP-MMA polymer concrete and verified that UP-MMA polymer concrete can evolve sufficient mechanical strength and modulus under a wide range of curing temperatures between −20 and 20 °C.

Polymer concrete, specifically when used in repair elements such as pavement/bridge deck patches and overlays, is subjected to millions of load repetitions mainly in flexure over the design period, which is one of the most important factors considered in the design procedure. There have been a number of research studies to evaluate fatigue behavior of plain concrete. Holmen [7] and Siemes [8] performed experimental studies on compressive fatigue performance of plain concrete. Hsu [9], Oh [10,11], and Shi et al. [12] examined the fatigue behavior of plain concrete subjected to flexural loading. Other previous studies [13–17] identified the fatigue behavior of special concretes such as fiber-reinforced concrete, self-compacting concrete, recycled aggregate concrete, and rubber concrete. On the contrary, little information has been available regarding the fatigue behavior of polymer concrete. Tavares et al. [18] investigated the fatigue behavior of epoxy polymer concrete reinforced with glass fiber-reinforced polymer rod. Recently, Bedi et al. [16,19] evaluated the fatigue performance of glass fiber reinforced polymer concrete composites and epoxy polymer concrete.

In recognition of the importance of fatigue behavior in the design process, this study is intended to identify the flexural fatigue performance of UP-MMA polymer concrete based on laboratory testing and statistical analysis. Furthermore, the relationship between applied stress levels S and the number of load repetitions to failure N (so called, S–N curve) is established to predict the fatigue life of UP-MMA polymer concrete at specified stress levels.

2. Experimental program

2.1. Materials

2.1.1. Binder

This study employed UP resin as a main binder for polymer concrete. The UP resin used was an ortho-type with a density of 1.13, a viscosity of 300 mPa·s (at 25 °C), an acid value of 20, and a styrene content of 40%. An MMA monomer is a transparent liquid, whose syndiotactic structure (a polymer chain structure with continuous regular patterns) increases under low-temperature radical polymerization. In this study, the MMA monomer was mixed with UP resin with specified proportions to formulate binders for polymer concrete. The physical properties of the MMA monomer used were as follows: a density of 0.942, a viscosity of 0.56 mPa·s (at 20 °C), and a molecular weight of 100 g/mol. Furthermore, an initiator was added to the binder to commence the hardening reaction of UP resin. The initiator used was a dimethyl phthalate (DMP) solution with 55% methyl ethyl ketone peroxide (MEKPO), whose specific gravity and active oxygen were 1.12 and 10, respectively. To promote the rate of inter-molecular hardening reactions, an accelerator was also added. The accelerator used was *N*,*N*-dimethylaniline (DMA) with a density of 0.942, a boiling point of 193–194 °C, a melting point of 1.5–2.5 °C, and a molecular weight of 121.18 g/mol. Because the UP resin generally undergoes large shrinkage of 6–10% in a linear scale during the setting, and thus may reduce the volume stability of structural components, a shrinkage-reducing agent (SRA) was adopted to mitigate the setting shrinkage at early ages. The SRA used was produced by dissolving polystyrene in a styrene monomer. The properties of the SRA were as follows: a density of 1.11, a viscosity of 3,100–4100 mPa·s (at 20 °C), and a nonvolatile matter content of 34–38%.

2.1.2. Aggregate and filler

Silica sand with a maximum size of 5 mm was used as aggregate. The physical properties of the aggregate used were: a grain size of 0.08–5 mm, an apparent density of 2.64, a unit weight of 1648 kg/m^3, and a fineness modulus of 3.09. The gradation curve for the aggregate is presented in Fig. 1. Prior to mixing, the aggregate was dried for 24 h at 110 ± 5 °C to keep the moisture content less than 0.1%. In addition, a filler was employed to fill the gap between aggregate particles in the form of "resin paste". The filler used was ground heavy calcium carbonate with 53.7% CaO, 0.25% Al_2O_3, 0.09% Fe_2O_3, 2.23% SiO_2, 0.66% MgO, and 42.4% loss on ignition (LOI). The physical properties of the filler were: a mean grain size of 13 μm, a density of 0.75, an absorption of 0.2 cc/gr, a water

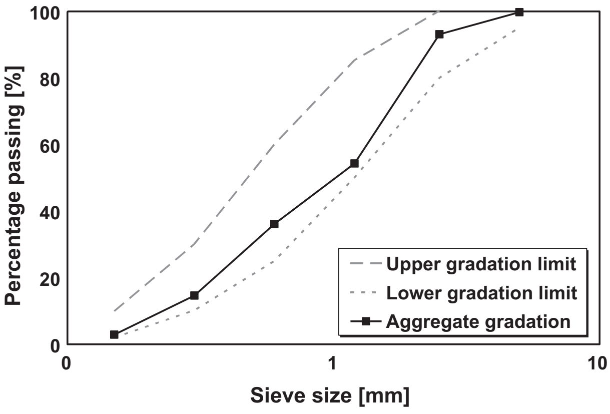

Fig. 1. Aggregate gradation for silica sand.