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Flexural-fatigue characteristics of pervious concrete: Statistical distributions and model development

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HIGHLIGHTS

- Performed flexural-fatigue test at different stress levels and frequencies.
- Found fatigue life significantly dependent on stress levels and stiffness.
- Observed a three-stage process for stiffness degradation and tensile strain accumulation.
- Distribution fitting indicated characteristic *infant mortality* type of failure.
- Developed laboratory fatigue models for fatigue life predictions.

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ABSTRACT

Pervious concrete pavements that are widely used as surface layers in low volume road applications such as parking lots, residential streets, etc. are subjected to repeated loads, which may undergo fatigue. Although most of the past studies have focused on the compressive strength and hydraulic properties, limited investigations have been reported in respect of fatigue in pervious concrete (PC). The objective of this study was to investigate the effect of stress levels and frequencies on the fatigue life and develop laboratory fatigue models of PC mixtures. The S-N curves indicated that power-function relation exists between stress levels and fatigue life of PC. The non-parametric and parametric methods indicated that the stress levels (0.70, 0.75, and 0.80) and stiffness were significant in affecting the fatigue life compared to the loading frequency in the range of 2–10 Hz. The fatigue relations of PC fitted with 3-Parameter Weibull and lognormal distributions indicated the characteristic *infant mortality* type of failure behavior, represented by initial portion of the reliability bathtub curve. The stiffness degradation and tensile strain accumulation depicted a three-stage process with rapid degradation in the primary stage, stable and constant degradation in secondary phase, and accelerated degradation in the tertiary stage. The laboratory fatigue models developed had *good-to-fair* statistical goodness of fit parameters ($0.65 \leq R^2 \leq 0.85$), which can be used to predict the fatigue lives of pervious concrete in case of non-availability of testing capabilities.

1. Introduction

Pervious concrete pavement systems are a class of rigid pavements that allow storm water to percolate through them owing to their macroporous internal structure. The main difference between pervious concrete and conventional concrete pavements lies in the fact that the amount of fines are reduced/eliminated in gradations used in pervious concrete paving mixtures. At present, pervious concrete pavements are the most promising materials for use as surface course layers in low volume roads such as residential streets, walkways, and parking lots, etc., where the traffic volume in terms of average annual daily traffic (AADT) is assumed to be ≤400. From its inception, pervious concrete has been studied under the various facets of mix design, strength characteristics, hydraulic properties, pore structure, durability, modeling, and non-destructive testing, chiefly to understand the material behavior and its suitability as a pavement material [1–8]. The most important property considered in designing a concrete material is compressive strength; in pervious concrete, the magnitudes of compressive strength vary from 3 to 25 MPa, where the porosities in most of the mixtures lying in the range of 15–35%, and more so, 20–25% as the preferred choice [9–14].

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However, it is noteworthy that pervious concrete pavements are subjected to flexural stresses and fatigue due to vehicular loads, and these aspects have not been studied extensively. In the past, researchers found that the axial fatigue behavior of polymer modification in pervious concrete was pronounced at higher stress levels [15]. But, pavement performance that is significantly influenced due to lower stresses, no significant differences were observed between fatigue lives of modified and unmodified pervious concrete mixtures at those stress levels. Chen et al. [16] studied fatigue behavior at three different stress levels of 0.70, 0.80, and 0.90, and found that polymer modification improved the fatigue life compared to those modified by supplementary cementitious materials. Recently, flexural fatigue tests on polymer-modified pervious concrete (with single sized aggregates: 27.5, 32.5, and 37.5 mm) for base course applications revealed that with increase in the aggregate size, the flexural fatigue life reduced.

Based on the current literature, no studies are available that have investigated the effect of frequency on the fatigue life of pervious concrete, although it is worth mentioning that few of the past studies indicate that there is no effect of frequency on the fatigue life of a conventional concrete in the range of 1.2–20 Hz [18,19]. But then, pervious concrete being very different from conventional concrete in terms of structural matrix and internal pore structure; it is essential to investigate the effect of frequency and stress level as these both parameters have direct relations with vehicular traffic over a wide variety of different classes of road. Further, a 2-parameter Weibull distribution is usually used to fit fatigue data for conventional concrete or other materials. However, any fatigue data acquired from mechanical tests possesses a minimum value of fatigue life, and therefore, the applicability of the 3-parameter Weibull distribution should be considered along with lognormal distribution as these two distributions are widely used in analyzing fatigue life data. Additionally, there are no readily available laboratory fatigue models for pervious concrete and therefore, would be required for future estimation of fatigue lives for quality control assessment. Further, these fatigue models would as well indicate the performance of pervious concrete pavements when subjected to traffic loads with suitable calibration.

With these gaps as the research lacunae, the objective of this study was to comprehensively investigate the fatigue behavior of pervious concrete paving mixtures by considering the effect of both frequency and stress level. Further, the fatigue database so developed was used to establish predictive equations (models). The research outline of the study included (Fig. 1):

- Design and production of pervious concrete beams with two gradations, one w/c ratio and one c/a ratio
- Estimation of density and porosity of pervious concrete beam samples
- Determination of flexural strength of pervious concrete beams
- Selection of stress levels and frequencies pertinent to field conditions
- Conducting fatigue tests at fixed stress level and frequency
- Understanding the effect of frequency and stress level using parametric and non-parametric methods
- Fitting distribution for the fatigue data and establishment of laboratory based fatigue models.

2. Research significance

Eller and Izevbekhai [20] in their first year performance report on pervious concrete test sections identified fatigue-type cracks

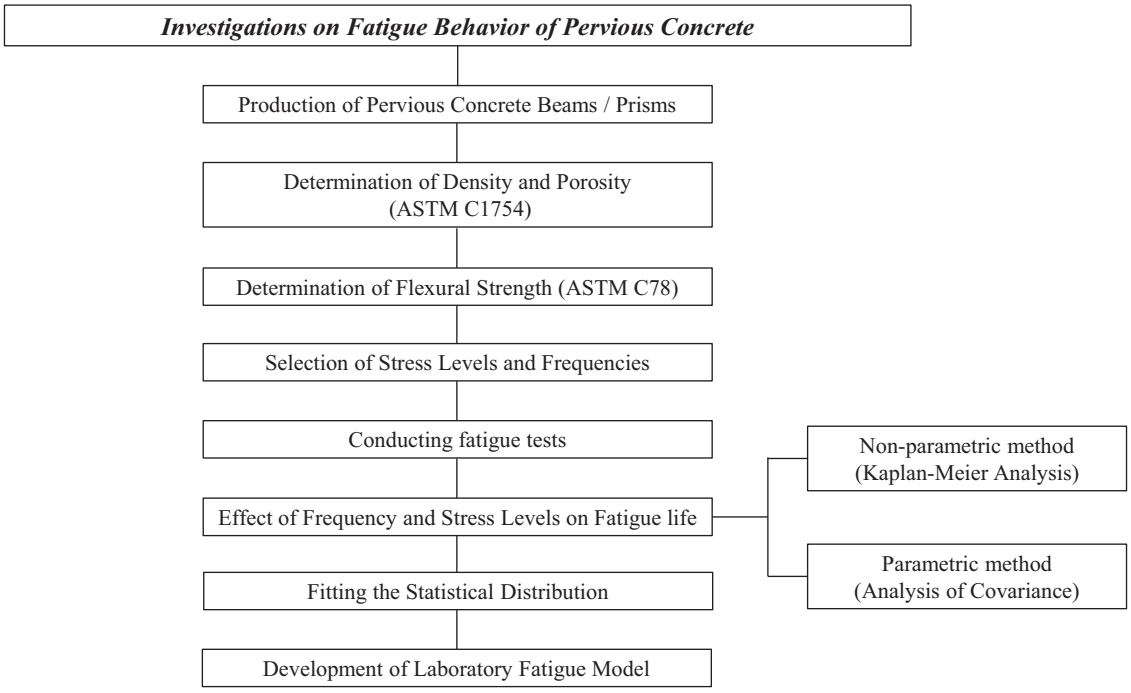

Fig. 1. Research Outline.

Table 1
Mix proportions for pervious concrete mixtures.

Gradation	w/c ratio	c/a ratio	Aggregate, kg/m^3	Cement kg/m^3	Water, kg/m^3
P2	0.35	0.25	1506.12	376.53	131.78
P6	0.35	0.25	1520.11	380.02	133