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Fracture behavior of pervious concretes: The effects of pore structure and fibers

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ABSTRACT

The fracture response of pervious concrete specimens proportioned for different porosities, as a function of the pore structure features and fiber volume fraction, is studied. Stereological and morphological methods are used to extract the relevant pore structure features of pervious concretes from planar images. A two-parameter fracture model is used to obtain the mode I stress intensity factor (fracture toughness) and the critical crack tip opening displacement of notched beams under three-point bending. The experimental results show that the fracture toughness is primarily dependent on the porosity of pervious concretes. For a similar porosity, an increase in pore size results in a reduction in fracture toughness. At similar pore sizes, the effect of fibers on the post-peak response is more prominent in mixtures with a higher porosity, as shown by the residual load capacity, stress–crack extension relationships, and resistance curves. These effects are explained using the mean free spacing of pores and pore-to-pore tortuosity in these systems. A sensitivity analysis is employed to quantify the influence of material design parameters on fracture toughness.

1. Introduction

Pervious concrete is proportioned using gap-grading the coarse aggregates and eliminating sand so as to create a high level of porosity (20–30%) and a network of large open pores (2–6 mm) in the material. The environmental benefits of pervious concretes have been well recognized with respect to stormwater run-off reduction and recharging groundwater [1–3], and tire-pavement interaction noise reduction [4–6] when used as surface courses in parking lots and pavements. These benefits have resulted in pervious concretes being increasingly used for load-bearing structures including pavements and overlays that require higher mechanical and durability properties. Unlike conventional concretes which are generally designed for the lowest possible porosity, pervious concretes are designed for a non-minimal porosity, and a high degree of interconnectedness in the pore structure so as to facilitate its functional demands. This, in turn, detrimentally affects the mechanical and durability properties of the material. A few studies have reported methods to improve the compressive strength [7–9] and freeze–thaw durability [10] of pervious concretes.

The major determinant of all the properties of pervious concretes is its pore structure, which generally has been considered to include the total pore volume fraction or the porosity, the characteristic pore sizes, and the degree of connectivity or tortuosity in the pore system. These pore structure features depend on the material design parameters (water-to-cement ratio, aggregate size, paste content, and degree of compaction). Traditionally, pervious concretes have been designed based

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Nomenclature

ϕ_v	volume fraction of pores (porosity)
ϕ_A	area fraction of pores
S_2 (l)	two point correlation function
l	length of line segment in two-point correlation (TPC) function
d_{TPC}	characteristic pore size from TPC
d_{crit}	characteristic pore size from granulometry
λ	mean free spacing of pores
L_A	length of pore features per unit area of the image
τ	tortuosity
ν_f	fiber volume fraction
K_{IC}	critical stress intensity factor (fracture toughness)
$CTOD_c$	critical crack tip opening displacement
CMOD	crack mouth opening displacement
P	load
S	span of the beam
E	elastic modulus
a_0	initial notch depth
a_c	critical crack length
a_e	effective crack length
Δa	crack extension (equal to $a_e - a_0$)
d	depth of the beam
b	width of the beam
$V(a_0/d)$; $V_1(a_c/d)$; $F(a_c/d)$	geometric correction factors
C_i	initial loading compliance
C_u	unloading compliance
W	self weight of the beam
G_R	strain energy release rate
α_0, α_1, α_2, α_3, β	coefficients of the statistical model relating K_{IC}, pore structure features, and fiber volume fraction

on a trial-and-error approach, but a sophisticated particle-packing based approach that relies on the virtual packing densities and volume fractions of the mixture components and the actual packing density of the mixture has been recently developed [11,12]. Extensive characterization of the pore structure in pervious concretes as a function of their material design parameters have been published [13–15], and the influence of pore structure on the mechanical [3,12,16] and transport [17–19] properties of pervious concretes have been brought out through experimental means and computer simulations of reconstructed three-dimensional structures [20,21].

This paper investigates the influence of the pore structure of pervious concretes and the incorporation of fibers on its fracture behavior. This is important because, as explained earlier, pervious concretes are increasingly being subjected to load-carrying applications. In a random heterogeneous two-phase material like pervious concrete with a dominant pore phase, it is expected that the pore structure (including the total pore volume, characteristic sizes, representative pore spacing in three dimensions, and pore-to-pore tortuosity) and its interaction with fibers influences the crack propagation resistance of the material. In this study, the fracture response of notched beams in three-point bending is characterized using an effective elastic crack approach (the two-parameter fracture model). The pore structure features of pervious concretes proportioned for different desired porosities are extracted using stereological and morphological principles [15,22] either from planar images or three-dimensional structures reconstructed from planar images. The combined influence of pore structure features and fiber volume on the fracture behavior of pervious concretes is examined so as to facilitate rational design of the material structure for desired performance features. A statistical model combined with a Monte-Carlo based feature sensitivity prediction method is reported, that helps ascertain the relative sensitivity of pore structure features and fiber content on fracture toughness.

2. Experimental program

2.1. Materials and mixtures

The pervious concrete mixtures were prepared using Type I/II Ordinary Portland Cement (OPC) and limestone coarse aggregates. In general, pervious concretes are proportioned using gap-graded aggregates. The most common aggregate sizes used are #4 or 4.75 mm (passing 9.5 mm, retained on 4.75 mm sieve), or 3/8″ or 9.5 mm (passing 12.5 mm, retained on 9.5 mm sieve) [4,12,19], which have been adopted in this study also. Maintaining a large open porosity necessitates a low