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Analysis by Ripley's function of the correlations involved during failure in quasi-brittle materials: Experimental and numerical investigations at the mesoscale

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ABSTRACT

The degradation of quasi-brittle materials encompasses micro-cracks propagation, interaction and coalescence in order to form a macro-crack. These phenomena are located within the Fracture Process Zone (FPZ). This paper aims at providing a further insight in the description of the FPZ evolution with the help of statistical analysis of damage. The statistical analysis relies on the implementation of Ripley's functions, which have been developed in order to exhibit patterns in image analyses. It is shown how a correlation length may be extracted from the Ripley's function analysis. Comparisons between experimental and numerical evolutions of extracted correlation lengths are performed.

1. Introduction

Fracture of quasi-brittle materials such as concrete or rocks is characterized by a macro crack surrounded by a damage zone. At the tip of the macro crack and ahead lies the so-called Fracture Process Zone (FPZ) which is a region of the material undergoing distributed damage. The size of the FPZ in these heterogeneous materials is large enough to influence the mechanical behavior of the structure significantly. It does not depend on the structural size, but it is rather controlled by the local heterogeneities in the material as well as by the geometry of the specimen and the stress conditions. Therefore, size effect, understood here as the dependence of the dimensionless nominal strength of a structure on its size, is observed (e.g. when geometrically similar structures are compared, see for example [1]).

Experimentally, this damage zone may be characterized with the help of several direct and indirect techniques. The localization of acoustic events that can be detected during crack propagation is one well established technique from which the FPZ can be visualized and characterized (e.g. [2–5]). The acoustic events generated during micro-cracking are recorded and post-processed in order to localize them with the help of time-of-flight algorithms. Hence, this technique provides information on the entire crack propagation process composed of distributed micro cracking and further coalescence into a macro

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Nomenclature

$\mathbf{B}$	matrix, which links the global and the localcoordinate systems
$\mathbf{D}$	material stiffness matrix
$\mathbf{D}_e$	elastic stiffness matrix
$\mathbf{K}$	secant stiffness matrix
A	lattice element cross-section area
a_0	three-point bending beam pre-notch length
b	three-point bending beam out-of-plane thickness
D	three-point bending beam depth
d	cell-size of the square grid for dissipated energy analyses
$D(i,j)$	euclidean distance between two points i and j
$d_{\min}$	minimum distance for acoustic transducers
e	distance between point C and the lattice element segment
E,γ	model parameters, which control Young's modulus and Poisson's ratio of the equivalent continuum
e_{ij}	edge effect correction factor between two points i and j
f	Kuhn–Tucker functional
f_t	tensile strength
G_f	meso-level fracture energy
H	distance functional used in Ripley's analyses
h	lattice element length
I	lattice element second moment
i,j	points
K	Ripley's function
K^{ran}	Ripley's function of a perfect randomly distributed set of points
L	Ripley's residual function
l	lattice element cross-section width
$L^{\text{disk}}(r,R)$	analytical approximation of the residual function of a distribution located in a unique disk of radius R
N	total number of points
point C	lattice material point
r,R_0,R	radius
R^*	optimum radius, which best fits the residual analytical function L^{disk}
r_{max}	position of the maximum of the residual function $L(r)$, which is defined as the extracted correlation length
S	surface of the analysis box
u,v,ϕ	degrees of freedom of a node: two translations (u,v) and one rotation (ϕ)
u_c	displacement jumps in the local coordinate system
u_e	degrees of freedom in the global coordinate system
v_{CMOD}	CMOD imposed velocity
w_f	initial slope of the softening curve
w_{cn}	crack opening
α	orientation of the element in the global coordinate system
ΔD_d	dissipated energy in a single lattice element
$\Delta\omega$	increment of damage parameter
κ	normal strain history dependent variable
ω	damage variable
$\overline{\sigma}$	effective stress vector
ϕ^d	concrete aggregate diameter
$\phi^d_{\min}$	minimum value of the explicitly described aggregate diameters
Π_{int}	inner perimeter
ρ	density of points
σ	stress vector associated to each degrees of freedom
σ_n	normal stress associated to u
σ_s	shear stress associated to v
σ_ϕ	stress associated to ϕ
ε	strain vector associated to each degrees of freedom
ε_0, c and q	model parameters
ε_n	normal strain associated to u
ε_s	shear strain associated to v
ε_ϕ	strain associated to ϕ