Etudes numériques et expérimentales des corrélations induites durant la rupture des matériaux quasi-fragiles

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Résumé :

La dégradation des matériaux quasi-fragiles met en jeu la création et la propagation de microfissures qui interagissent et coalescent afin de former une macro-fissure. Ces phénomènes sont localisés au sein de la zone d'élaboration (Fracture Process Zone – FPZ). Cette communication vise à préciser la description de l'évolution de la FPZ à l'aide d'une analyse statistique du processus d'endommagement. L'analyse statistique est basée sur l'utilisation de fonction de Ripley qui ont été développée initialement pour caractériser des motifs particuliers en écologie spatiale. On montre qu'une longueur de corrélation peut être extraite à partir de ces analyses par fonction de Ripley. Une comparaison numérique et expérimentale de l'évolution de ces longueurs de corrélation extraites est enfin proposée.

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 spatial ecology. 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.

Keywords : Fracture, Quasi-brittle materials, Fracture Process Zone, Boundary effect, Mesoscale, Mesoscopic model, Experimental, Acoustic emission, Ripley's functions

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 behaviour 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.

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. 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 crack.

As far as modeling is concerned, continuum based approaches and discrete or mesoscale models are available. The first one involves a characteristic length, which controls the size of the FPZ. In recent models, however, it has been pointed out that this internal length is not constant during the fracture process and also that it is influenced by boundaries, which could be expected since experimental works on fracture in concrete underline the influence of boundaries on the fracture energy. The second approach relies on a mesoscale description of the material and on an explicit description of the heterogeneities in the material. As opposed to the continuum approach, mesoscale models do not introduce any characteristic length. At the scale of a lattice element or a discrete element, softening is introduced as a local property.

Grassl and co-workers [1] demonstrated that mesoscale modeling was very efficient at describing not only size effect on the peak load, but also the entire load deflection response of bending beams. Four geometrically similar sizes and three different notch lengths were considered. The experimental data obtained by Grégoire et al. [2] could be quite accurately described, once the model parameters at the mesoscale level had been calibrated for one notch length. In addition, the authors used this model for studying the incremental distribution of the dissipated energy densities, and they were able to track the evolution of the fracture process zone in the structure, depending on the size of the beams and on the boundary conditions.

In addition, Grégoire and co-workers [3] demonstrated that this mesoscale approach is also capable to capture the local failure process realistically. Three point bending experiments coupled with acoustic emission analyses provided global responses of the same bending beams and local data in the form of the distribution of the acoustic events and its evolution in the course of fracture. The experimental data obtained by Grégoire et al. [3], in term of energy dissipation maps and histograms of the distances between damage events, could be quite accurately described with the same set of model parameters. Particularly, the agreement between the distributions of the relative distances between damage events show that the mesoscale model depicts the fracture process zone and its evolution during failure in a very consistent way compared to acoustic emission data. Unfortunately, and contrary to the case of direct tension, these histograms cannot be interpreted easily because the effect of the strain gradient in bending beams cannot be easily separated from the interaction between damage events that may develop in the course of fracture.

The purpose of this paper is to provide a further insight in the description of failure with the help of statistical analyses of damage. The statistical analysis relies on the implementation of Ripley's functions [4], which have been developed in order to exhibit patterns in image analyses. First, it is shown how Ripley's functions may be used in the context of damage mechanics to extract correlation length between damage events. Then, comparisons are presented showing the evolution of extracted correlation lengths during mesoscale numerical simulations and experimental three point bending tests where damage events are localized by acoustic emission techniques. Finally, numerical investigations of correlation length evolutions upon failure are presented for both direct tension and three point bending specimens. Results show that the computed correlation length is not constant during failure and significant differences may be observed depending on the type of loading applied to the same specimen.

References

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