

Fracture Mechanics—Theory, Modeling and Applications

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1. Introduction

The field of fracture mechanics was developed during the throes of World War II, and since then, it has been a very active area of research. This is a very energetic and vibrant field because fracture processes are relevant for a vast range of engineering applications spanning different temporal and length scales. Depending on the application, material fracture and fragmentation may be either a desirable feature (for example, for the purpose of hydraulic fracturing operations), or something that is to be avoided at all costs (for example, in key components of mechanical systems). In some other instances, fractures are already present and must be accommodated through novel design (for example, in the case of earthquake ruptures occurring in the Earth's crust). Because of this wide spectra of motivation, there is a continuous need for the fracture mechanics research community to gain more insight on how fractures are created, evolve, and interact with themselves and with material microstructures. In addition, there are still many remaining questions about how fracture propagation, growth, and interaction impact overall material behavior, and how to develop accurate models to predict this behavior.

The objectives of this Special Issue focus on gathering the latest advances on the theoretical, numerical, and application-based fronts for the study of fracture initiation, propagation, arrest, interaction, and fragmentation in engineering materials in general, including but not limited to ceramics, geo-materials, granular materials, and metals.

2. Review of Issue Contents

As mentioned, this Special Issue covers theoretical, numerical, and experimental research on different aspects related to fracture mechanics. This is covered in 11 original papers that reported novel advancements in the study of damage evolution and fracture behavior in a wide range of materials and applications. While many of these efforts bridge different methods, here, we introduce them in broad categories of theoretical, numerical, and experimental research.

2.1. Theoretical Research

In [1], Margolin took a close look at a statistical crack model (SCM) and extended it by incorporating a model for crack interactions, namely coalescence. In addition, Margolin created an array code that represents a single computational cell with a statistical distribution of cracks that can be used as a numerical laboratory to study SCMs and test the validity of key assumptions within these damage models. Using this approach key conclusions could be drawn about the prediction of failure as a function of damage, specifically that failure occurs at much lower levels of damage that typically predicted.

2.2. Numerical Research

Caldwell et al. [2] presented a benchmarking study for impact cratering applications between a finite-discrete element method and a hydrodynamics approach, the latter of which is the more traditional approach for modeling impact cratering events. Both 2D and



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3D simulation results were presented, and the 3D results included cases in which the impact angle was oblique. While differences between the codes exist, namely, in how damage is nucleated and evolved within the different meshing strategies, both codes showed good comparison against both analytical solutions and previously published numerical results.

In [3], Chen et al. proposed the modified void nucleation and growth model (MNAG model) in which the original void nucleation and growth model (NAG model) was extended by added a term to account for the void coalescence. The MNAG model was parameterized with molecular dynamics (MD) shock data of single crystal and nanocrystalline Ta. Results from the MNAG model were compared both to the MD results, and to the results from several other well-known damage models. While the other damage models could successfully capture some aspects of damage evolution, only the MNAG model successfully captured all stages of void evolution, including nucleation, growth and coalescence. This new model could provide improved fidelity in damage modeling within large length scale codes, such as hydrodynamic codes.

Godinez and Rougier [4] presented an assimilation method, based on the ensemble Kalman filter, that was used for the calibration of a subset of interfacial strength parameters used in the combined finite–discrete element method to simulate the dynamic behavior of a granite sample when tested at high rates of strain via a split Hopkinson pressure bar experiment. Interfacial strength properties are key for the simulation of fracture and fragmentation processes, but in some cases, they are not very easy to obtain experimentally. This paper introduces a novel way to calibrate these properties based on experimental data.

Lei et al. [5] developed a generalized traction–separation formulation that can be used in cohesive zone models commonly used in numerical codes based on main stream numerical methods, such as the combined finite–discrete element method and the finite element method. The authors presented the details of the new formulation, along with a series of testing and benchmark examples featuring fracture and fragmentation processes in glass under dynamic loading.

Min et al. [6] numerically studied fracture processes of rough concrete rock joints under direct shear loading conditions, using an implementation of the 3D combined finite–discrete element method that had been parallelized for GPGPU (general-purpose graphic-processing-unit) architecture. The authors first presented the results of a material property calibration exercise that was used as a basis for the rest of the analysis. For the direct shear simulations, they identified two main mechanisms for shear resistance for this type of joints: asperity sliding and asperity degradation.

Seon et al. [7] presented a combined numerical and experimental study on the design and testing of honeycomb structures that can be inserted into bollards. This work showed that in-plane honeycomb inserts within bollards can improve shock absorption, and thus decrease damage to vehicles and their occupants.

Shishlyannikov and Zvonarev [8] presented a theoretical and experimental study of cross-cutting patterns on potash ore. In their work, they characterized the main failure mechanisms for this type of operation and compared them to the results obtained using the staggered-cutting technique. The analysis also reported on savings on the potash ore mass cutting, decrease in the average load of the cutter, and other production related benefits for the cases where cross-cutting techniques are employed.

2.3. Experimental Research

Hagengruber et al. [9] conducted a series of experiments to analyze the sandstone failure mechanisms under a confined Brazilian test setting. More precisely, the authors concentrated on the material behavior on the confined tension region defined in the maximum and minimum principal stress space, i.e., $\sigma_1 - \sigma_3$. The study was also complemented by a numerical modeling effort, which showed very good agreement with the experiments. The authors determined that the strength values recorded by this method are also dependent on the intermediate stress, σ_2 , which is well represented by the Mogi–Coulomb strength criterion.

Islam et al. [10] studied the stresses on the gears of a pepper transplanter picking device in order to determine the best combination of material type and dimensions with the aim of predicting their fatigue life. For this, they used a combination of numerical analysis via the finite element methods and tests specified by the American Gear Manufacturers Association. They concluded that high- and middle-carbon steel materials are suitable for this application.

Li et al. [11] reported results from Brazilian disc tests completed on five different types of rock and employing three different loading configurations. These experiments were combined with digital image correlation (DIC) in order to capture the strain and displacement fields during loading. This study investigated the validity of the Brazilian disc test and found that the fracture behavior is dependent upon both the loading conditions used and the properties of the material being tested.

3. Conclusions

This Special Issue compiles new and innovative research, addressing important open questions within the fracture and damage community. The described studies span a wide range of applications, methods, loading conditions and materials, illustrating how broad the issue of accurately accounting for damage and fracture evolution really is. While there are still many open research questions, this Special Issue provides a detailed look at several of these issues and correspondingly advances the field.

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