Dynamic fragmentation using the Discrete Element Method

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The Discrete Element Method (D.E.M.) \cite{1,2} is an efficient approach for treating fracture mechanics, especially when multiple contacts between cracked surfaces occur. The aim of this presentation is to study via D.E.M. the physics of fragmentation, which is an important damage mechanism in a variety of applications, including ballistic impacts, explosions, landslides during earthquakes, etc. An essential feature of our approach is the coupling between the Discrete Element Method and a cohesive law to model cracking and dissipative mechanism.

In a first part, we have adopted the cohesive law in \cite{3}, which is a variation of the Camacho-Ortiz \cite{4} irreversible linear-decreasing cohesive law (Fig. 1). In order to validate the discrete method to treat dynamic fragmentation, we choose to study the dependance of the dissipated fracture energy during fragmentation as function of mesh density, for one and two-dimensional numerical models.

In this first model, we simulate a one-dimensional 50 mm ceramic beam to an intense tensile loading, up to fragmentation. The beam is modelled with discrete particles and our results are systematically compared to continuum modelling (Finite Element, Zhou, Molinari and Ramesh \cite{3}) results in order to validate our D.E.M. approach. We also compare our average fragment size to energy models (Grady, Glenn and Chudnovsky \cite{5}) (Fig. 2). We show that the fracture energy dissipated in the D.E.M. model converges to a well-defined value which is function of the imposed strain rate. This value is proportional to the number of fragments.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Irreversible linear-decreasing cohesive law}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Comparison results of the average fragment size}
\end{figure}

Then, we simulate a 2D model, in which a two-dimensional ceramic plate is submitted to an intense tensile loading, up to fragmentation. The fracture energy dissipated and the number of fragments converge, but only for the models with low strain rates. Indeed for the high strain rates, the models require a large number of particles to have a convergence of dissipated energy and the number of fragments.

From this first part, it appears that achieving numerical convergence for a 3D specimen of a similar size will be out of scope.
In a second part, we introduce another cohesive law: a probabilistic cohesive law [6]. In this law, defaults are introduced by a Weibull law:

\[ \lambda_t[\sigma(T)] = \lambda_0 \left( \frac{\sigma(T)}{\sigma_0} \right)^m, \]

with \( m \) the Weibull modulus, and \( \frac{\lambda_0}{\sigma_0} \) the Weibull parameter.

The kinetic law for damage variable \( D \) is expressed in a differential form to be implemented in the discrete element code:

\[ \frac{d^2X}{dt^2} = \lambda_t[\sigma_i(t)] n! S(kC)^n. \]

With \( k \) a form parameter, \( C \) the celerity of the material, \( n \) the dimension of the problem.

![Figure 3: Convergence of the dissipated energy for a 1D model](image1)

![Figure 4: Distribution of the fragments size in function of the meshes density](image2)

In order to validate our approach, we have chosen to study the same models as for the linear-decreasing cohesive law. With the multi-scale model, the dissipated energy and the distribution of the size of the fragments converge with low number of particles. So the dissipated energy is not dependent of the meshes density. For the performances of the multi-scale model, we observe a gain factor of 100 between the model with the linear-decreasing cohesive law and the multi-scale probabilistic cohesive law. For example, with a \( 10^5 \) s\(^{-1} \) strain rate, to have a convergence of the dissipated energy at 5%, the first model requires 5000 particles and the multi-scale model 500 (Figs 3 and 4). These results are very encouraging and make possible the modelling of the dynamic fragmentation in two and three-dimensional models with high strain rates.

References