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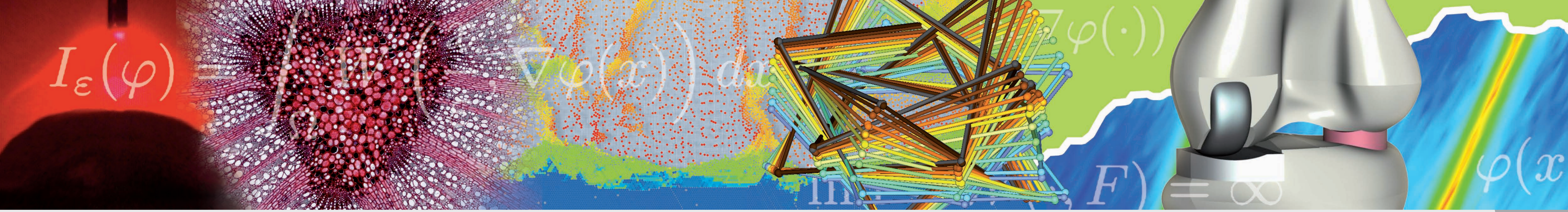
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# Fragmentation of grains under impact

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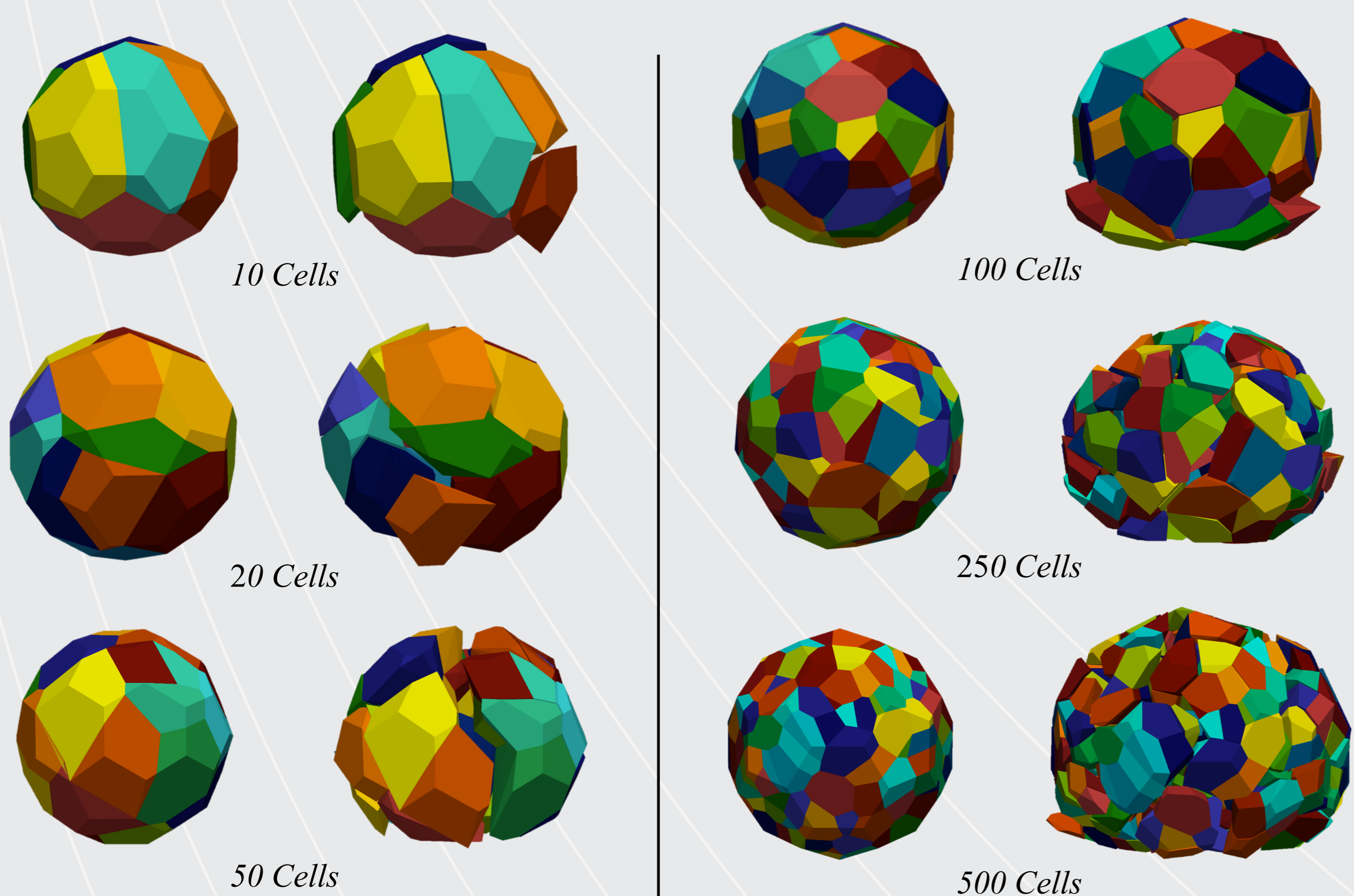
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Many industrial granular processes involve desired or undesired **fragmentation** of grains. However, despite experimental measurements and numerical modeling approaches, the mechanisms of single grain fragmentation and its effects on the behavior of granular materials are still poorly understood. In this work, we investigate the fracture and fragmentation of a single grain due to **impact** using three-dimensional **Contact Dynamics** simulations. The grains are assumed to be perfectly rigid but modeled as an assembly of bonded polyhedral Voronoï cells. The strength of the bonds represents the internal cohesion of the grain along normal and tangential directions. The inter-cell joints can open either in tension or by slip when the fracture strength is reached. A series of simulations for a range of different values of parameters (number of cells, cohesion, impact velocity) were performed. The **efficiency** of the fragmentation process was defined as the ratio of the energy dissipated by fracture to the kinetic energy at impact. It find that the efficiency increases with the number of cells. We also show that the efficiency is inversely proportional to the internal cohesion. Finally, the impact velocity maximizing the efficiency is found to be 0.08 m/s for two grains tessellated with 20 and 100 cells.

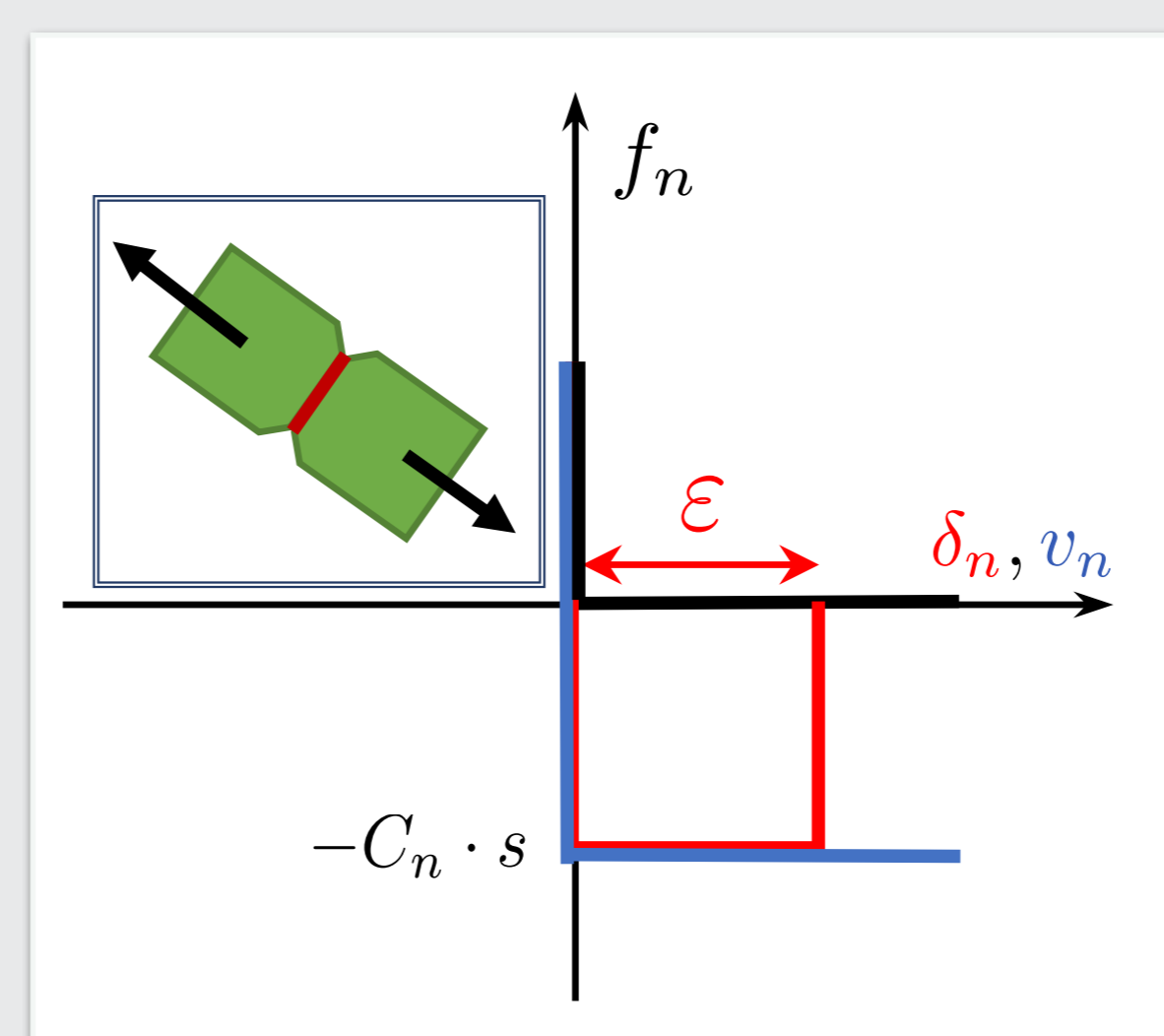
## Crushable particle model

The simulated grains have an external shape of a semi-regular polyhedron. The grain is composed of polyhedral cells generated by means of Voronoï tessellation using the package NEPER. The number of cells determines the maximum number of fragments that can be generated. In order to study the effect of this variable in the fragmentation process, several grains composed of different numbers of cells were released to impact a rigid plane.

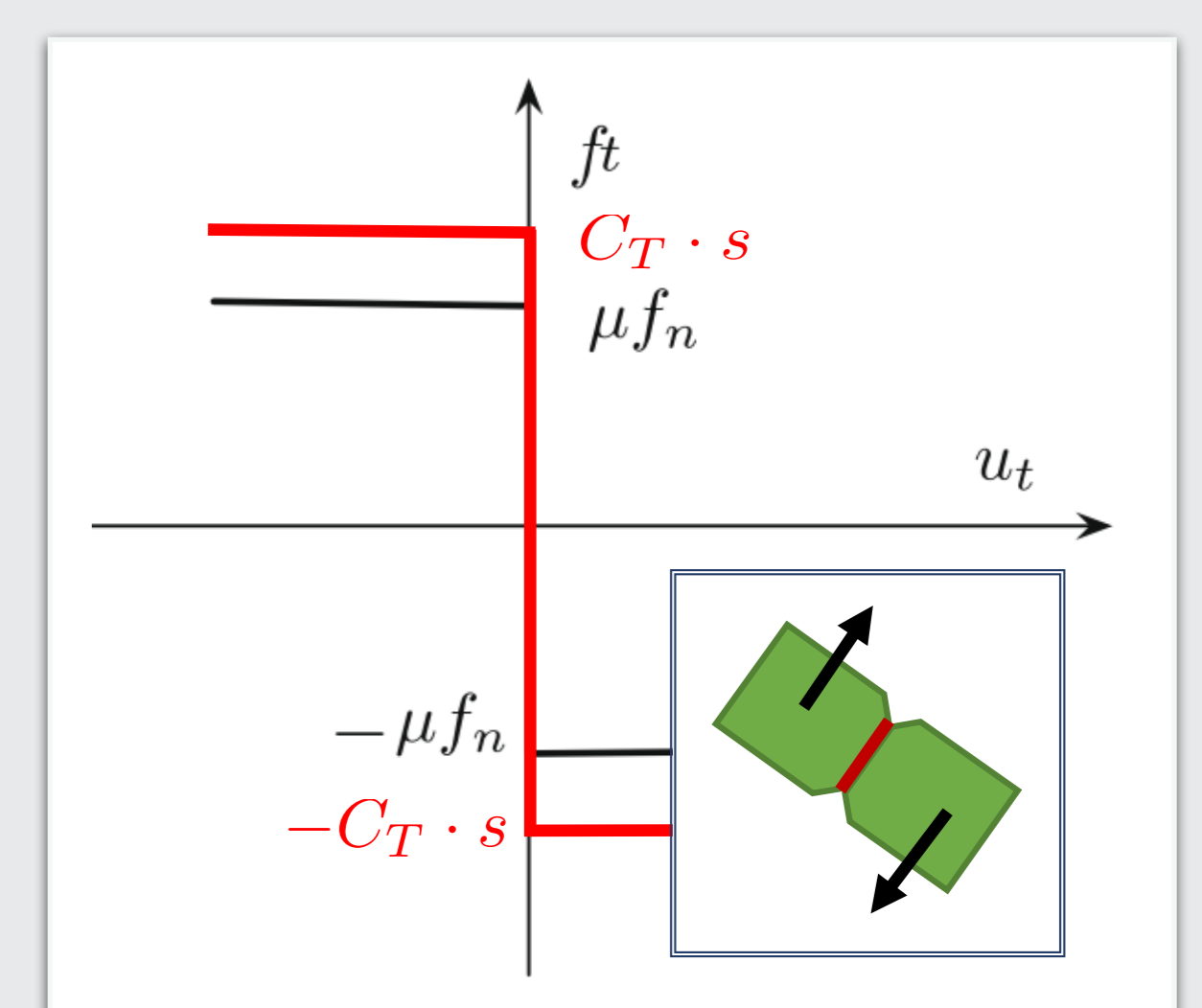


## Contact Dynamics Method

In the Contact Dynamics method, the equations of dynamics are integrated for all the particles considered as rigid-bodies by taking into account the complementary relations of Signorini and Coulomb's friction law (see below). The red and blue lines represent the cohesive contact law whereas the black line represents the contact law for a broken contact. The cohesive behavior is governed by two independent strengths thresholds:  $C_n$  (acting in the normal contact direction, preventing tensile failure) and  $C_t$  (acting in the tangential contact direction, preventing shear failure). The effective contact strength depends on the contact surface ( $s$ ). The cohesive behavior is conserved until a gap between cells reaches a  $\varepsilon$  value.



Signorini's Condition



Coulomb's friction Law

## Results

Fig. (a) shows the evolution of the different energies during particle impact and fragmentation. The energy dissipated by fracture is always below the energy lost by inelastic collisions. Energy dissipated by friction is negligibly small. Fig. (b) shows that the efficiency increases and levels off with the number of cells. Fig. (c) displays the efficiency as a function of impact velocity. We see that the efficiency increases with velocity and then declines with a maximum at a velocity of 0.08 m/s. This behavior is a consequence of the fact that the efficiency a quadratic function of velocity whereas the forces leading to fragmentation and dissipation by fracture are proportional to the velocity. Fig. (d) shows that the efficiency declines as the bond strength between fragments increases.

