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# Modeling particle breakage inside rotating drums

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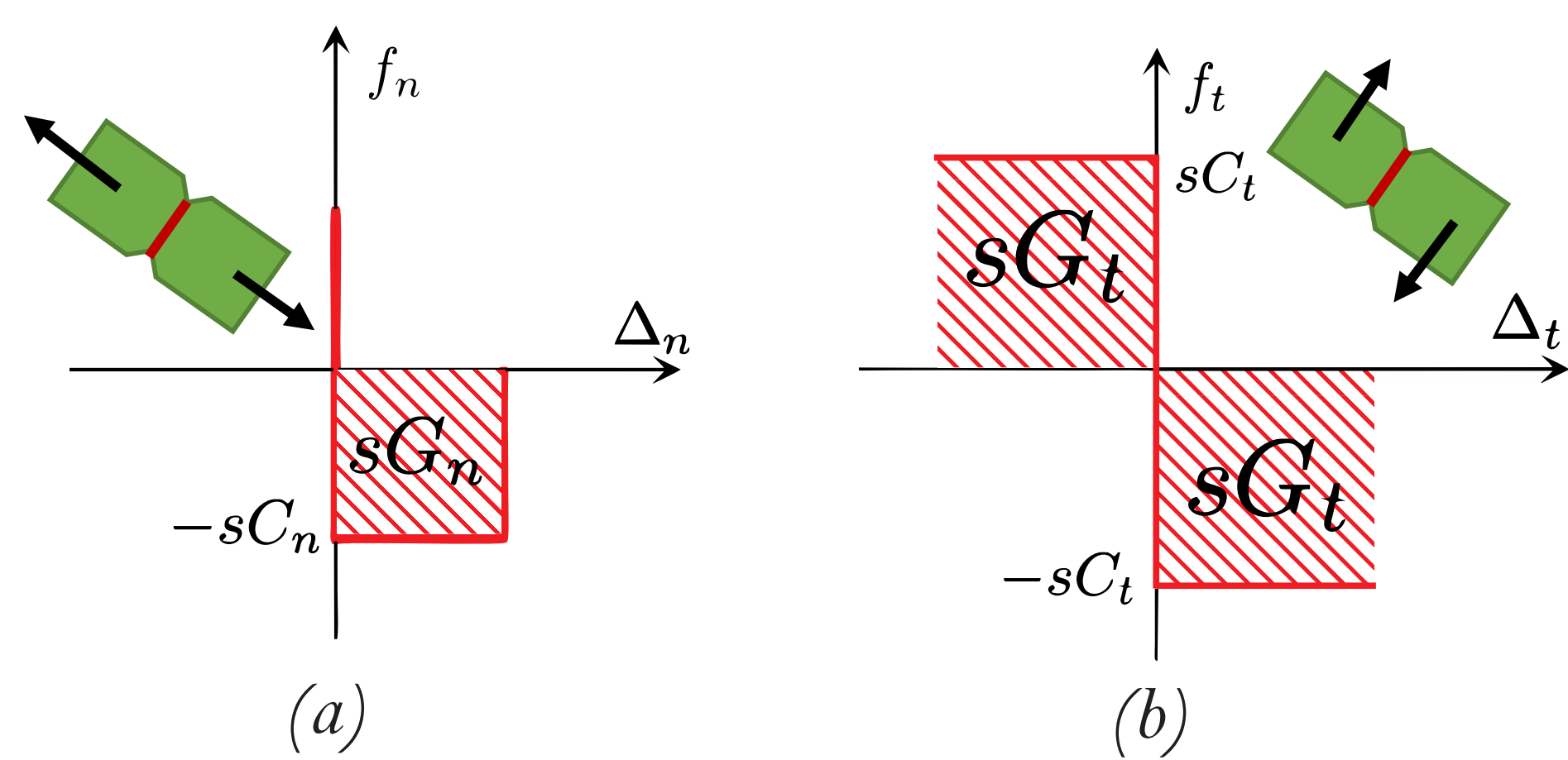
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Rotating drums are systems often used in industry for processes that require mixing and grinding of materials. Laboratory tests show that the extrapolation of the observed behavior to the industrial scale does not produce the expected results in terms of grinding performance (particle size distribution, specific surface, etc). It is difficult to measure experimentally the crushing evolution, but, using numerical simulations, we are able to follow the breakage processes that take place at different scales. We use the Contact Dynamics method (CD) and the Bonded Cell Method (BCM) in order to simulate breakable grains. The study of a single grain impact enhances the understanding of the breakage process under **dynamic conditions**. Then, the evolution of material properties is compared for different rotating drum configurations.

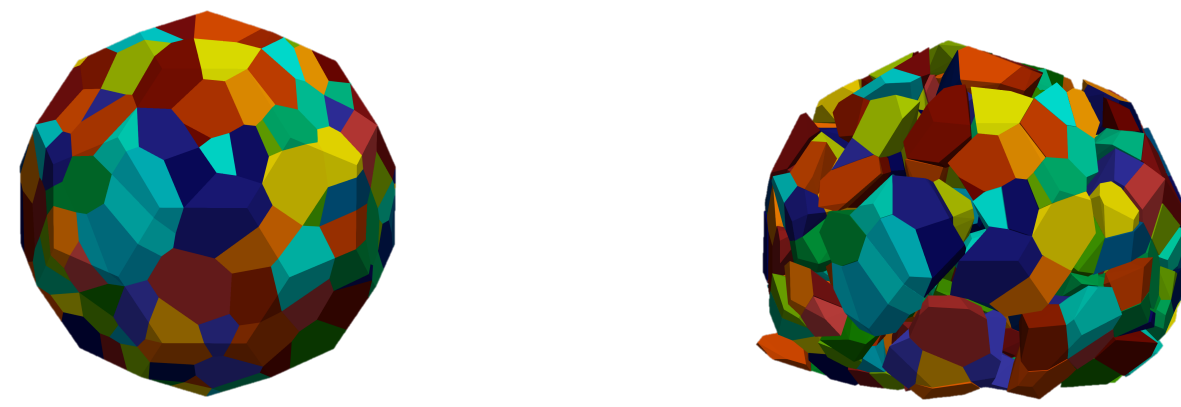
## Crushable particle model (BCM)

A particle is considered as an assembly of independent cells generated using Voronoï tessellation. The intercell cohesive behavior is governed by two independent strength thresholds:  $C_n$  (preventing tensile failure) and  $C_t$  (preventing shear failure). The effective contact strength depends on the contact surface ( $s$ ). Once one of the thresholds is reached, the contact can break irreversibly when the work performed by the cells relative movement reaches the fracture energy ( $G_f = G_n = G_t$ ). Then, the non-cohesive interfaces follow a purely frictional contact law.



Cohesive contact law between cells in (a) normal direction (tension) (b) tangential direction (shearing)

Tests of a single particle impacting a rigid plane were performed for different values of impact velocity, cells configuration and values of fracture energy  $G_f$ .



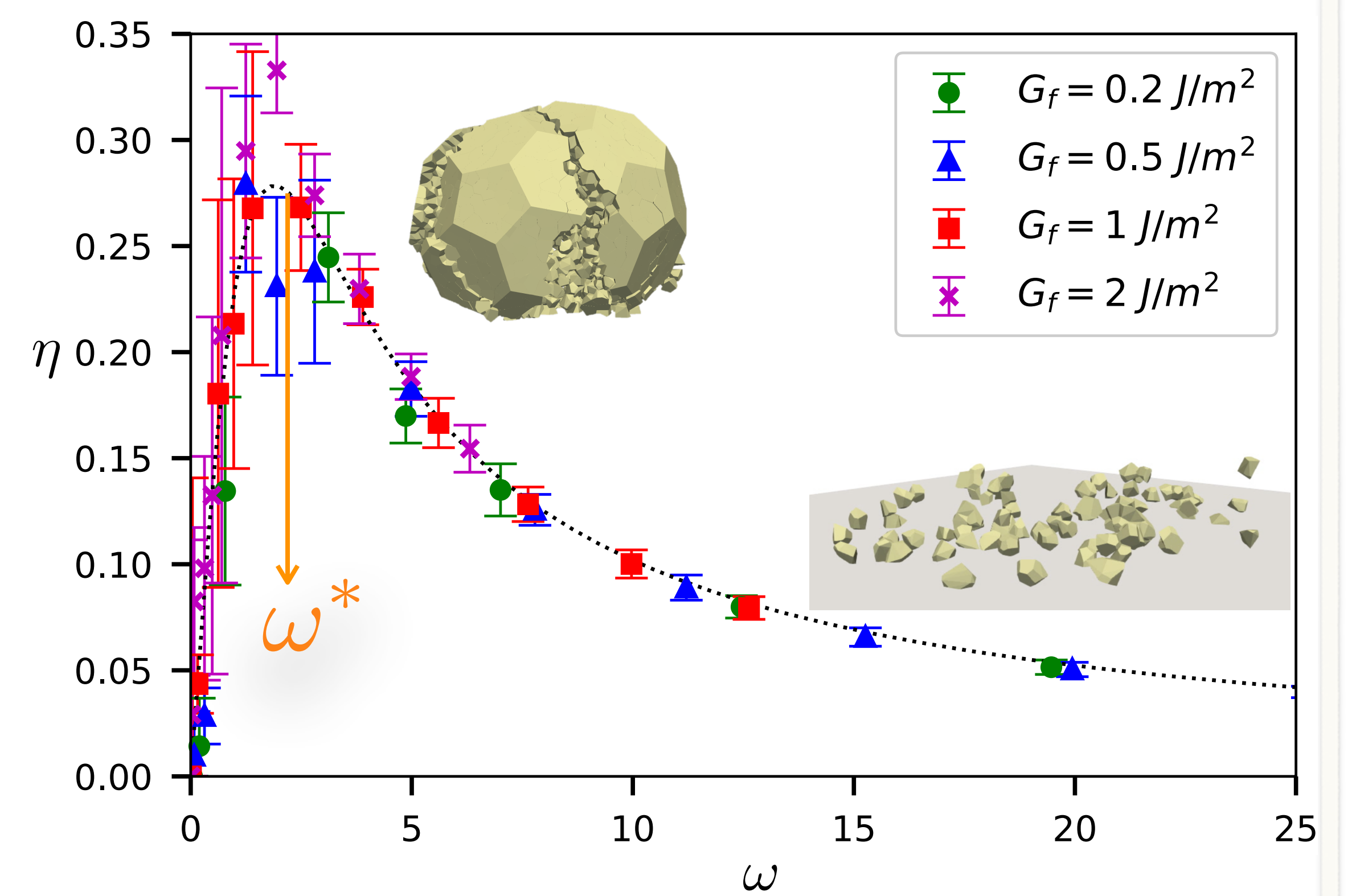
Particle generated with 500 cells before and after the impact, each color represents a cell

$$\eta = \frac{W_f}{W_k^-} \quad \omega = \frac{W_k^-}{W_f^T}$$

The fragmentation efficiency  $\eta$  is defined as the ratio of fracture ( $W_f$ ) and impact energy ( $W_k^-$ ).  $\omega$  is the impact energy normalized by the available fragmentation energy ( $W_f^T$ ).

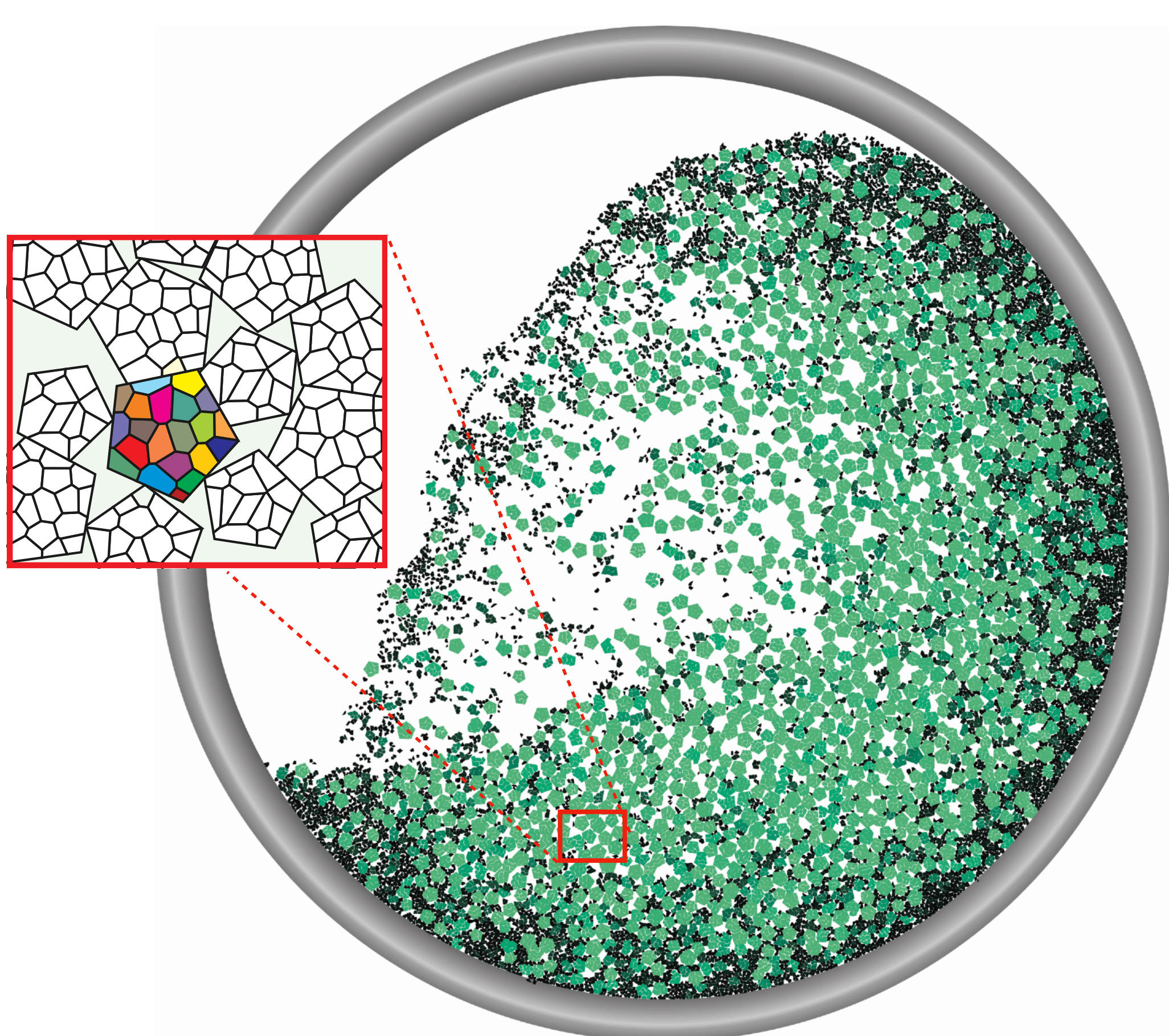
We find that all the data collapse when plotted as a function of  $\omega$ , the peak of maximum efficiency coincides at  $\omega^*$  for all the tested values of fracture energy  $G_f$ . Further analysis show that for  $\omega < \omega^*$  the injected energy is mainly used for surface generation, while for  $\omega > \omega^*$  it is mostly transformed on fragments kinetic energy.

## Single particle impact

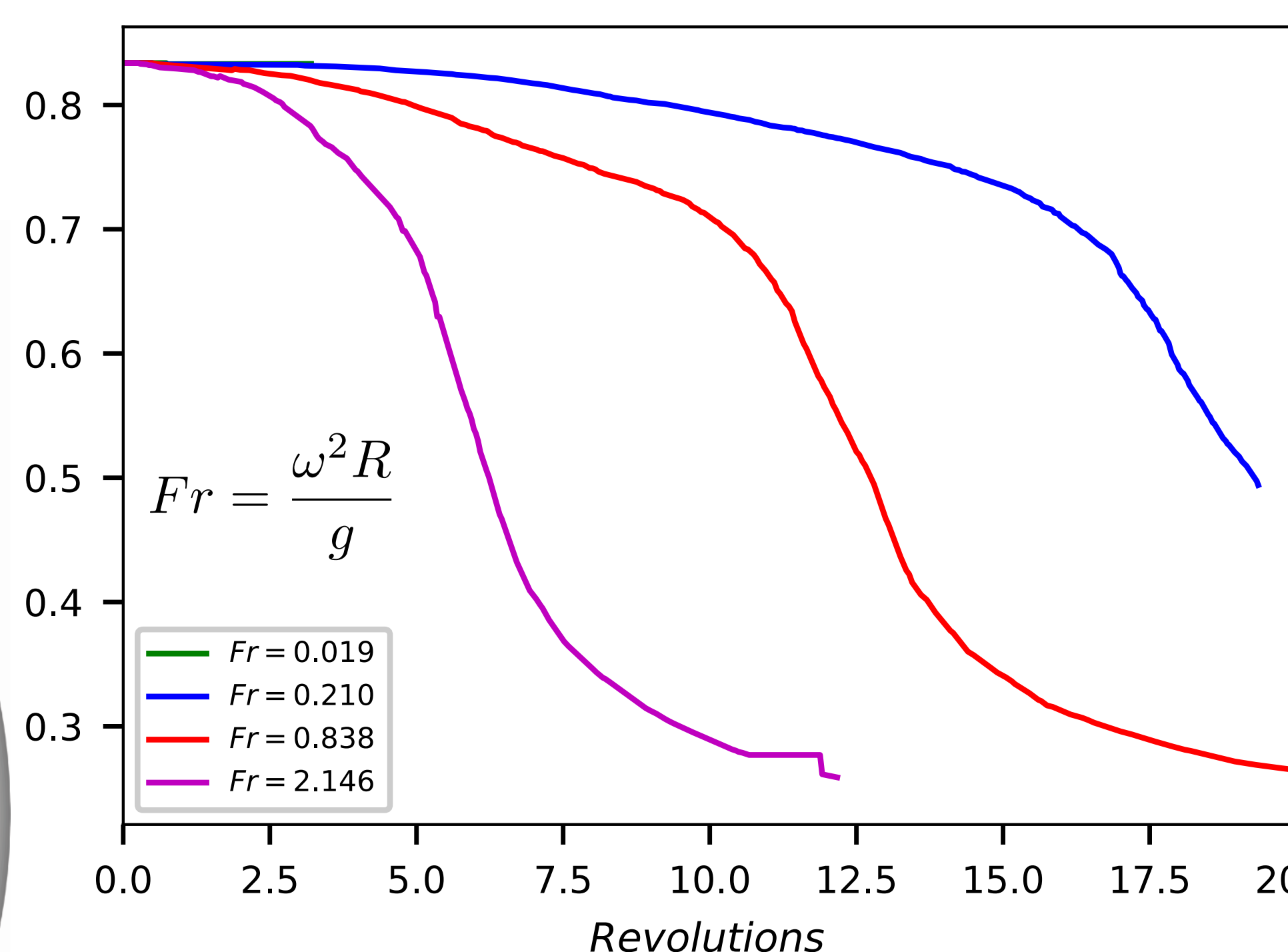


Fragmentation efficiency ( $\eta$ ) as a function of the normalized impact energy ( $\omega$ ). The error bars represent the standard deviation of 10 independent tests

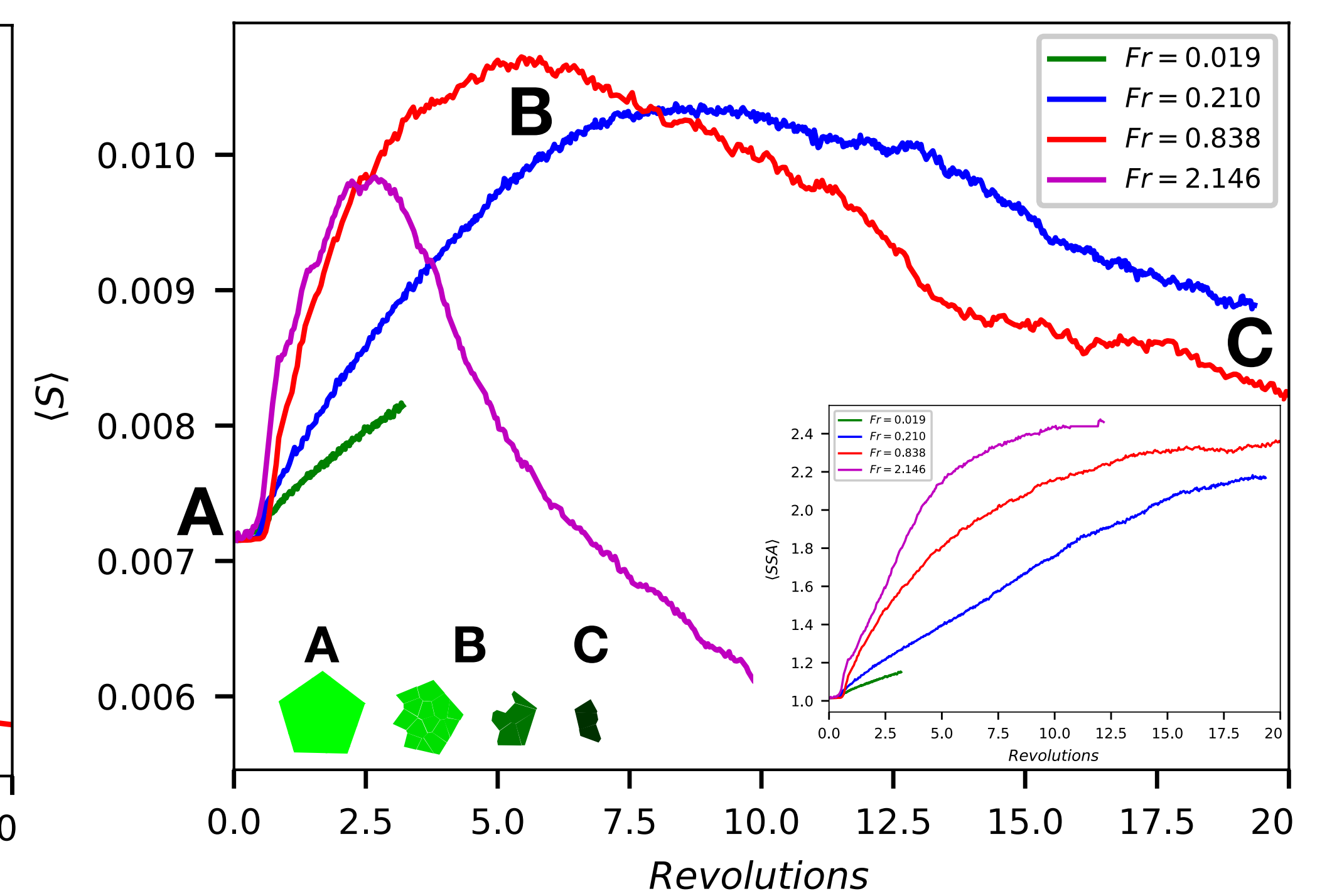
## Particle fragmentation in a rotating drum



Snapshot of an assembly of breakable particles modeled with BCM inside a rotating drum. The color represents the damage: bright green for intact particles, black for fully crushed particles.



Evolution of the mean particle size normalized by the initial grain diameter. Tests performed with different Froude numbers ( $Fr$ ), changing only the rotational speed ( $\omega$ )



Evolution of the mean particle surface  $S$ , for drums rotating at different speeds. Inset: Development of mean particle specific surface ( $SSA$ )

Numerical simulations of breakable particles inside a rotating drum were performed for a set of rotation speeds. As expected, this process is faster when higher rotation velocities are applied. Also, we found that the specific surface increases during the grinding, while the surface exhibits an unmonotonic evolution. In the beginning, the breakable particles have a pentagonal shape visualized as bright green (A). As the breakage starts and proceeds, rougher particles are produced that have lost few cells and therefore, the mean surface increases (B). After the peak, the particles start losing their roughness and becoming rounder and smaller, as presented with a dark green color (C).