BREAKAGE MODELLING

Peter Rizkalla
Leap Australia

Rahul Bharadwaj
Rocky DEM, Inc.

ABSTRACT

The breakage model used in Rocky DEM has various applications for accurately simulating the fragmentation and degradation of particles in bulk materials handling equipment. Rocky's unique ability to simulate arbitrary-shaped convex polyhedral particles enables it to preserve both mass and volume in the breakage processes, providing increased accuracy over other commercial DEM codes. This paper explains how the breakage model is applied in Rocky, and provides cross-industry examples and best practices for its optimal application.

INTRODUCTION TO PARTICLE BREAKAGE

Particle breakage or particle degradation is a process that involves splitting a larger particle into several smaller fragments. This can be desirable or undesirable depending on the application.

For example, in the mining industry there are bulk materials handling equipment whose primary purpose is to crush or break larger particles into smaller ones to reduce particle size enough to prepare the material for further processing downstream in the plant. There are many different variants available, including a High Pressure Grinding Roll (HPGR), gyratory crusher, cone crusher, and jaw crusher, all of which have essentially the same purpose. In many cases, the material being crushed is often very hard and abrasive, which places further requirements on the wear liners and other components. In addition, SAG mills and ball mills are types of comminution devices typically installed downstream of crushers and are used for grinding crushed rock into even finer particles. Crushers and grinding mills are all applications where breakage is desirable.

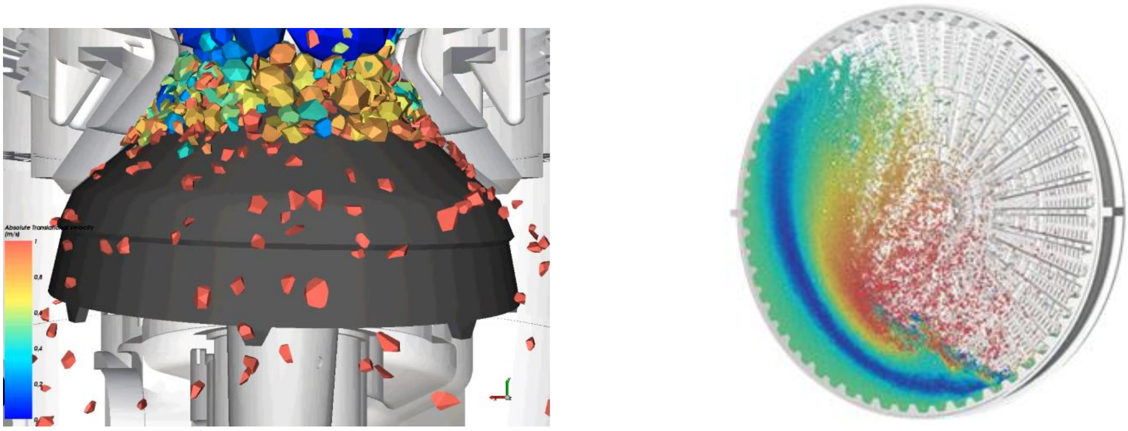

Figure 1: Rocky DEM simulation of a cone crusher (left) and SAG mill (right)

On the other hand, particle breakage must be avoided or minimized when wanting to guarantee a certain quality of material being conveyed but also to ensure that dust generation (arising from very fine materials) is kept to a minimum as this can have environmental and/or health implications. Besides mining, several other industries deal with applications requiring careful consideration of breakage; for example the spray coating and impact forces of pharmaceutical tablets or the seasoning of chips in a rotating mill for food processing.

THE ROCKY DEM BREAKAGE MODEL

Breakage modelling is very important in simulations of granular flow in order to represent real behaviour. The breakage model currently implemented in Rocky DEM is based on a combination of the Ab-T10 approach [1] developed by JKRMC (for the mining industry) and Voronoi Fracture particle subdivision algorithm [2] (used primarily in the movie special effects/gaming industry).

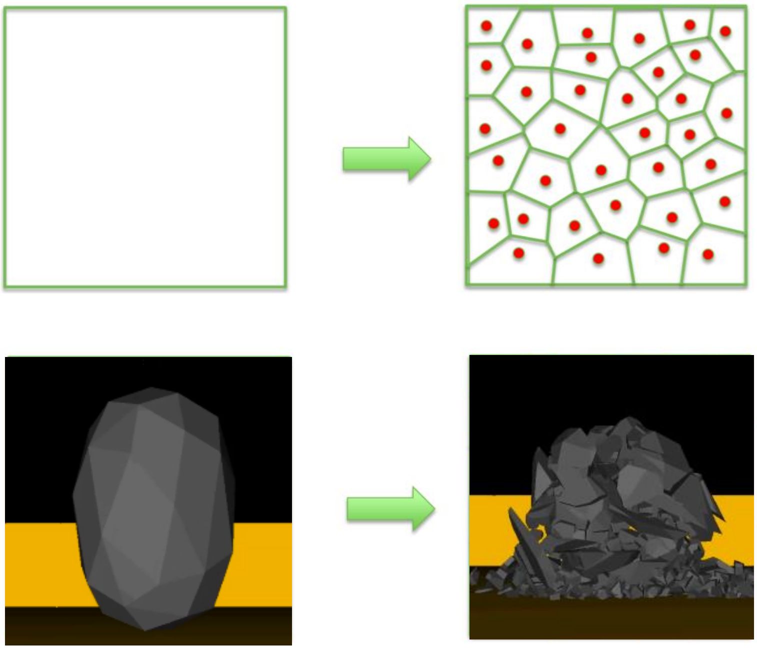

Figure 2: 2D schematic of the Voronoi fracture algorithm (top) and 3D simulation of a single particle breakage event (bottom)

Unlike many other DEM computer codes where particles of either spherical or other preset shape are used, Rocky uses arbitrary-shaped convex polyhedrons and therefore can preserve both mass and volume during the breakage process. Typically in DEM, there are two approaches that can be adopted to model the breakage process. The first approach is to physically model the breakage process including stresses and crack propagation within each particle, which would determine the fragment size and distribution. The second approach is to make certain assumptions and use empirical and probabilistic relationships to model the breakage process. The first approach, although highly accurate, usually requires higher computational resources, therefore making the second approach by far the most preferred for industrial purposes. The simulation process for breakage is described below.

For every particle that is in contact with other particles and/or walls, the total specific energy of this contact, e, is calculated. This is an inherent output of DEM simulations. If this energy is larger than the minimum breakage energy of the particle, e_{min}, which is determined as

$$e_{min} = e_{min,ref}\left(L_{ref}/L\right) \tag{1}$$

where L is the particle size, $e_{min,ref}$ is the minimum specific energy for a reference particle size and is a material constant and L_{ref} is the reference particle size. The contact specific energy minus the minimum breakage energy is added to the cumulative energy of previous contacts e_{cum} such that

$$e_{cum}{}^{new} = e_{cum}{}^{old} + \max(0, e - e_{min}) \tag{2}$$

The breakage probability of the particle P, is calculated via the formula

$$P = 1 - e^{-[S(L/L_{ref})\, e_{cum}]} \tag{3}$$

where S is the particle breakage strength parameter (or selection function coefficient), which is a material constant. If the particle is broken then the fragments are generated following the Voronoi fracture algorithm according to the distribution specified by the T_{10} protocol, which specifies the percentage of particles passing a screen whose size is 10% of the original particle size, given as

$$T_{10} = M\left[1 - e^{-[S(L/L_{ref})\, e_{cum}]}\right] \tag{4}$$

where M is the maximum T_{10} value and is a material constant. The full fragment size distribution is determined from the value of T_{10} by assuming a certain shape and size distribution according to Gaudin-Schumann. After the Particle Size Distribution (PSD) is calculated, a set of random distributed seed points are created inside each particle and a Voronoi region is created enclosing each point as shown above in Figure 2. The minimum size of fragments after breakage is limited by the user

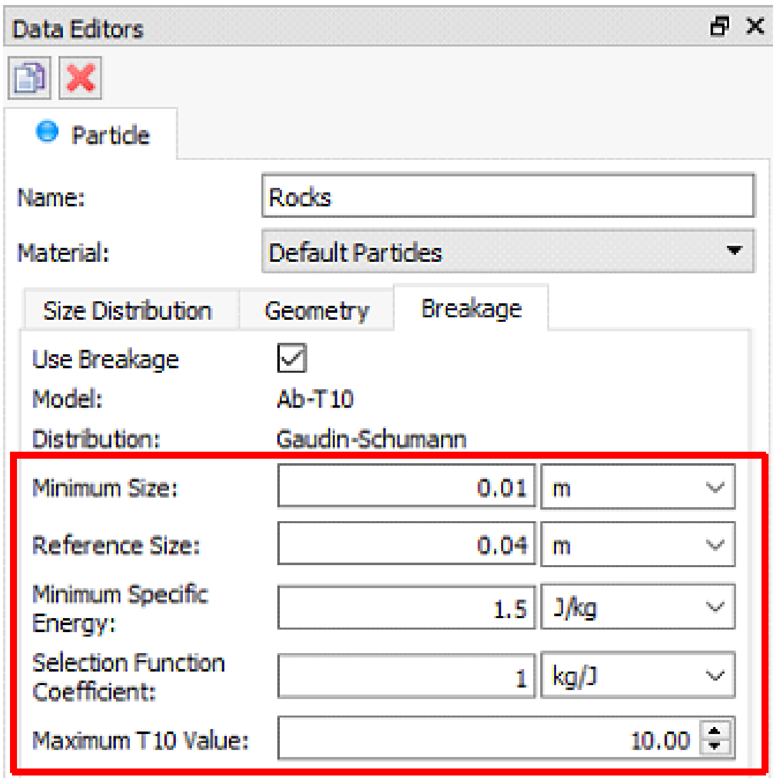

Figure 3: Data Editors panel in the Rocky User Interface showing activation of the breakage model. Input parameters are marked in red. Material constants are determined from standard drop weight tests.

BEST PRACTICES FOR USING BREAKAGE IN ROCKY DEM

When using the breakage model in Rocky DEM, the following points should be considered:

- The values of M and S may not be available separately, which is quite typical in the mining industry. Rather it is usual to have the value of the product M x S, usually found as A x b, since separate breakage probability and product fineness are not really important, hence only the combined value is given.
- To calculate A x b in [tons/kWh], the following units and expression should be used:

$$A \times b = 3600 \cdot M \ \cdot S \cdot \left(\frac{L}{L_{ref}}\right)$$

where M is expressed as a percentage and S has units of [kg/J].

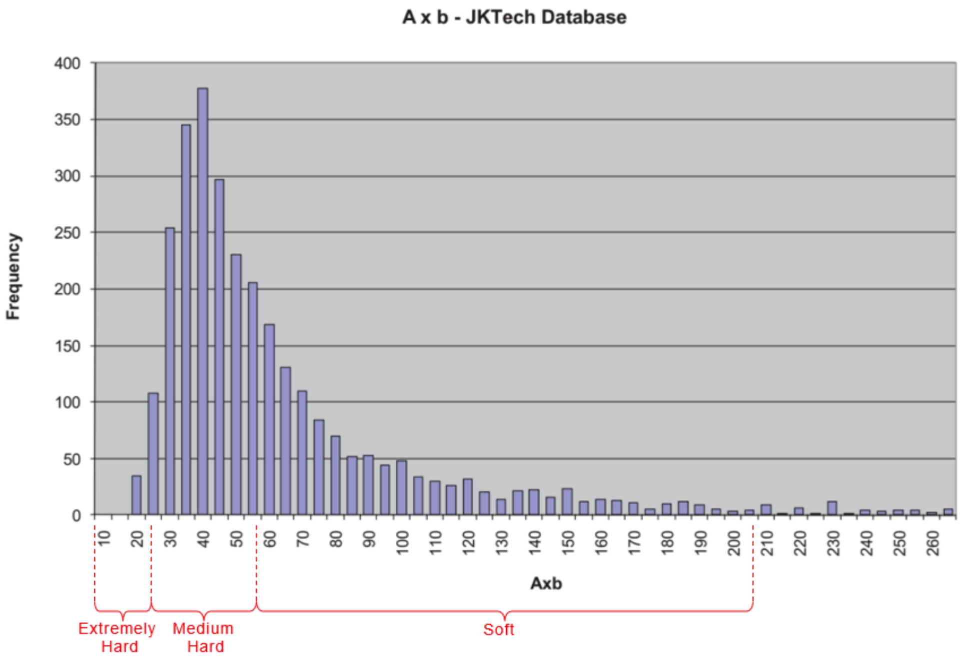

Figure 4: Example of A x b values for a sample material from JKTech Database [3].

- The particles sizes used for typical drop weight tests are around 1 inch particles. Therefore, the reference size is around 1 inch or 0.025 m.
- The maximum T_{10} value, M, can be in the range from 0-100%; however, the range is typically somewhere between 10-30%. When the particles break, they will break in finer pieces with higher M values.
- Breakage probability increases as the selection function, S, increases. The greater the value of S, the easier it is to break the particles. S typically ranges between 2e-04 to 6e-03 kg/J (calculated over the range of Axb from JKTech).
- The smaller the value of the minimum size defined, the more accurate the product size distribution will be, but at the expense of increased computational cost.
- The minimum breakage energy is quite difficult to obtain. It is a very important parameter in cases where particles break mostly upon multiple impacts, such as in AG or SAG mills.
- For cases where breakage occurs mostly from a single compression or impact event (such as crushers, impact crushers, or HPGRs), the minimum breakage energy is not too important and can be left as default (very small value) or even set to zero.

EXAMPLE APPLICATION: USING BREAKAGE TO EVALUATE TRANSFER CHUTE DESIGNS

Being able to predict material degradation in transfer chutes is very important for two main reasons: 1) reducing the environmental impact of dust created by fine particles, and 2) maintaining the overall quality of the material. Until now, these sorts of problems have received very little attention in DEM because of their complexity. But with the Rocky DEM breakage model, these problems can now be accurately simulated and better understood.

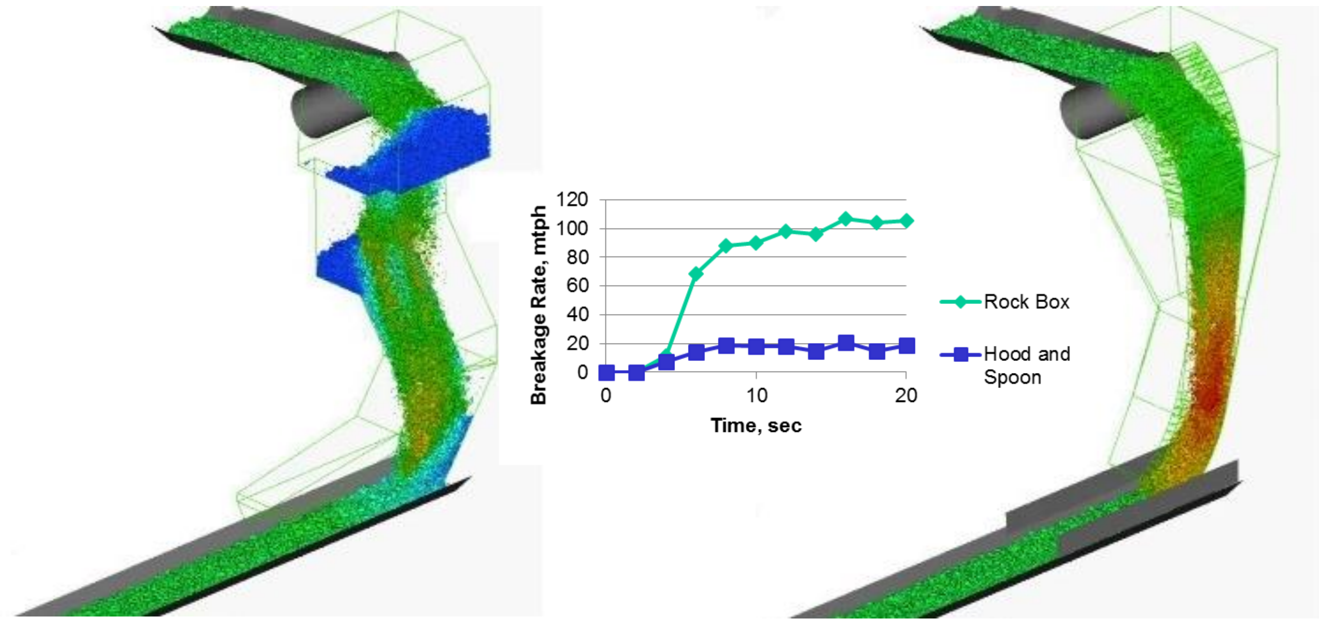

Figure 5: Comparison of two chute geometries simulated in Rocky DEM: a rock box (left) and hood and spoon (right). Particles are coloured by velocity. Graph shows relative breakage rate.

The Rocky breakage model was used to simulate the flow of coal through two different transfer chutes, namely, a classic rock-box and a hood and spoon configuration as shown above in Figure 4. Apart from chute geometry, all simulation parameters were kept the same. The simulation consisted of over one million particles, half of which were non-round and breakable and the other half were round and non-breakable. The breakage properties for coal were determined via drop weight tests at different heights on an impact plate. Despite the higher particle velocities, the hood and spoon configuration endured much less breakage compared to the rock box chute as shown by the plot of breakage rate.

EXAMPLE APPLICATION: VALIDATING BREAKAGE ACCURACY BY SIMULATING AN HPGR

Another application where the accuracy of Rocky's breakage model was validated is presented below. High Pressure Grinding Rolls (HPGRs) are devices that are typically used in the mining and minerals industry. The HPGR is a displacement device, therefore it is expected that the results for force and power draw will depend upon particle stiffness. In this application, the particle stiffness was calibrated with respect to a specific force. For the purpose of these simulations, the roll gap was fixed and particle stiffness was varied until the predicted and measured values of the force were in close agreement, as the results presented below illustrate.

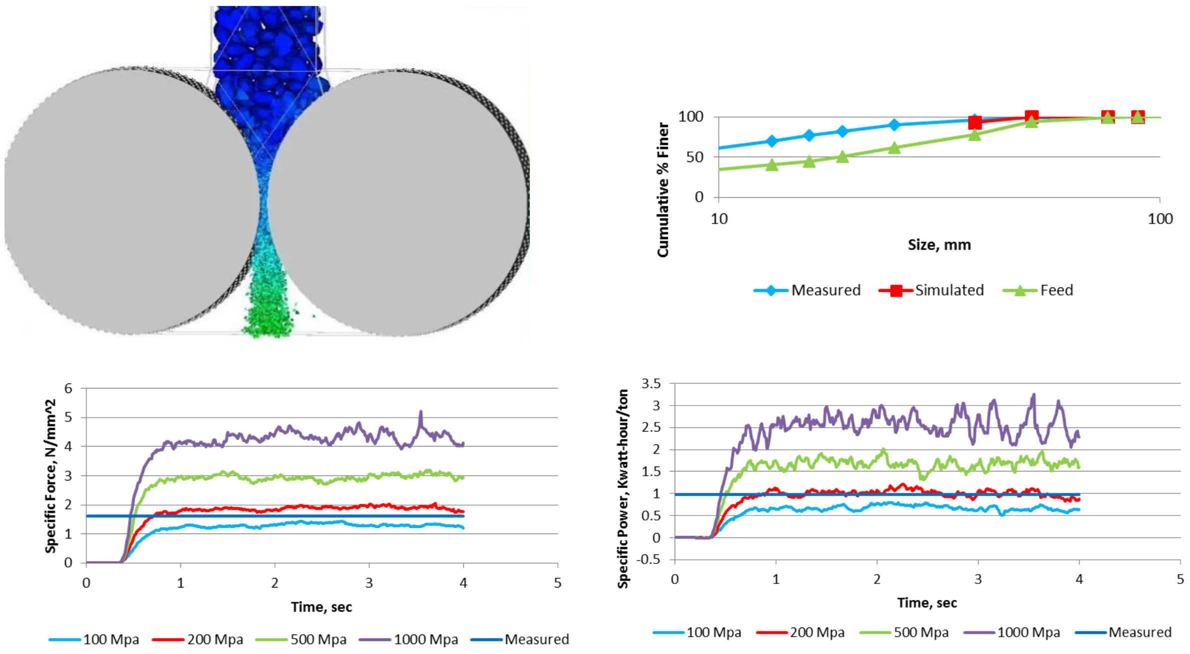

Figure 6: Rocky DEM simulation of a HPGR (top left). Results show particle PSD after breakage (top right), specific force (bottom left), and specific power (bottom right).

As can be seen in the plot of specific force, a value of 200 MPa for the particle stiffness correlates very well to experimentally measured values. Similarly, the specific power for the same particle stiffness is also in close agreement to experimental results. This also confirms that unlike other applications with much lower consolidation forces (for example, transfer chutes and conveyors), the correct stiffness value plays an important role in obtaining correct quantitative results for force and power draw. This means that the default value of 100 MPa in Rocky is normally conservative for cases that do not involve breakage or high contact forces.

The PSD obtained after breakage further confirms the accuracy of the breakage model. In the interests of computational time, the PSD was limited to four discrete groups, however this was still in good agreement with the experimentally measured values. Finally, it is important to note that whilst breakage modelling can increase the accuracy of your predictions, the computational power to process these simulations can be substantially higher, although this can be addressed by taking advantage of GPU processing to reduce the solve time or time-to-solution.

MORE INFORMATION

If you would like more information or are interested in watching a webinar on Breakage Modelling in Rocky, please register you details here.

REFERENCES

[1] Shi, F. N.; Kojovic, T. 'Validation of a model for impact breakage incorporating particle size effect', *International Journal of Mineral Processing*, 82-3, p. 156-163. 2007

[2] E. Coumans, 'Destruction', *Game Developers Conference*, San Francisco, March 5-9, 2012

[3] SMC Test Report on Three Samples from Hazen Project 11708, JKTech Job No. 13012/P5. February 2013

[4] Rocky Training Manual, Lecture 3 – Advanced Models