ANALYSIS OF GRANULAR FLOW DYNAMICS IN BALL MILL

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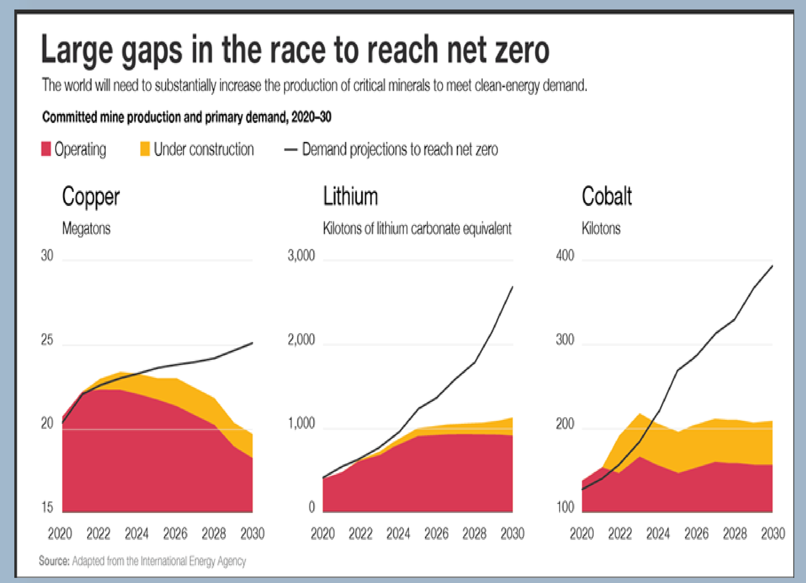
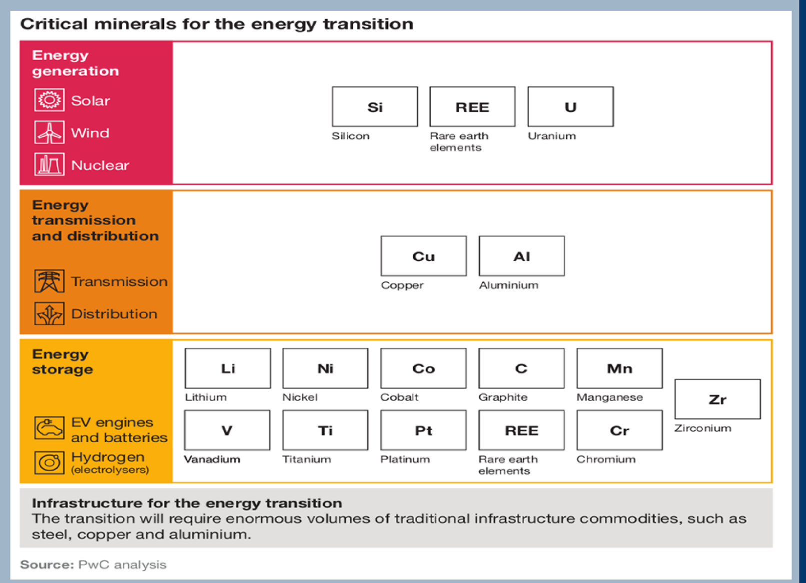
ABSTRACT

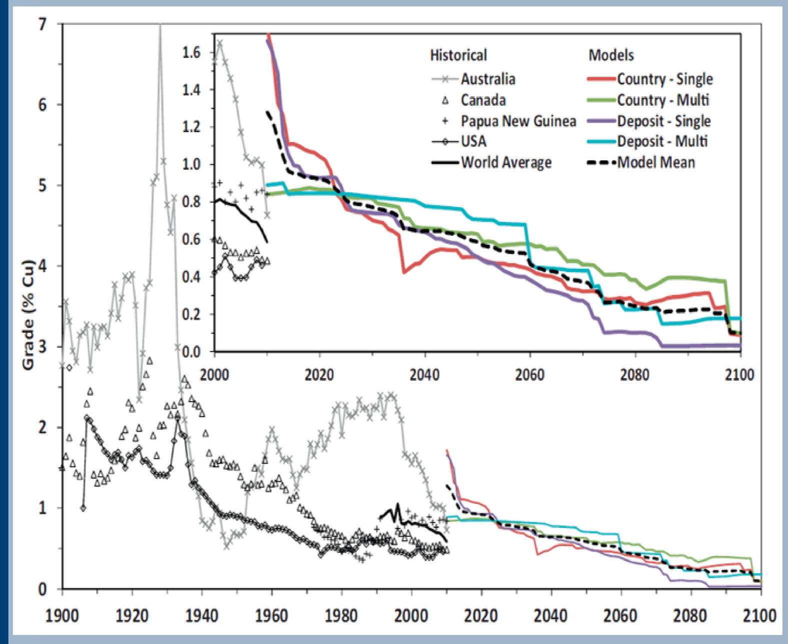
In this study, the Discrete Element Method (DEM) is employed to investigate the dynamics of granular flow in a ball mill under varying operational conditions. The stress distribution within the mill is analyzed to provide insights into regions of high-stress concentration that are critical for particle breakage. A particle breakage probability function is developed based on the von Mises stress criterion and frictional shear work, enabling a more precise prediction of breakage events. The results can inform the design of more efficient mills and contribute to a deeper understanding of particle breakage mechanisms in granular flows.

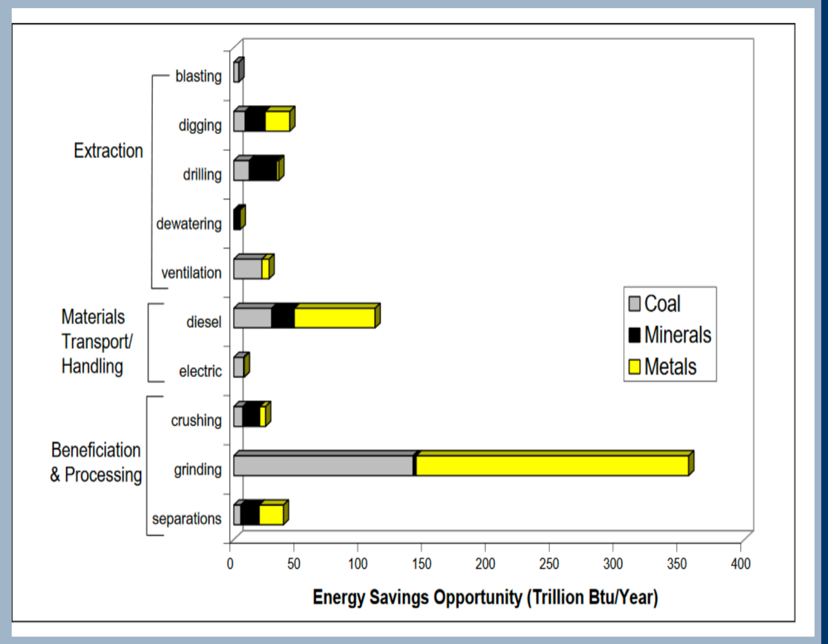
INTRODUCTION

Global demand for net-zero energy transition requires more mining activities, of which most of the ores are low-grade, so they need to be fine ground to liberate the desired minerals. However, as a unit operation, grinding and comminution contribute one of the highest energy consumption rates; the mining sector alone was responsible for an estimated 1.8% of global electrical consumption in 2015. However, efficiency value can be as poor as 1%-2%, so reducing energy use while maximizing grinding quality is of paramount interest to the industry, especially considering the current global economic and energy climate. Ball media milling is an extensively used grinding technique. To improve the efficiency and performance of the mill, we study the grinding process in this work using the Discrete element method.









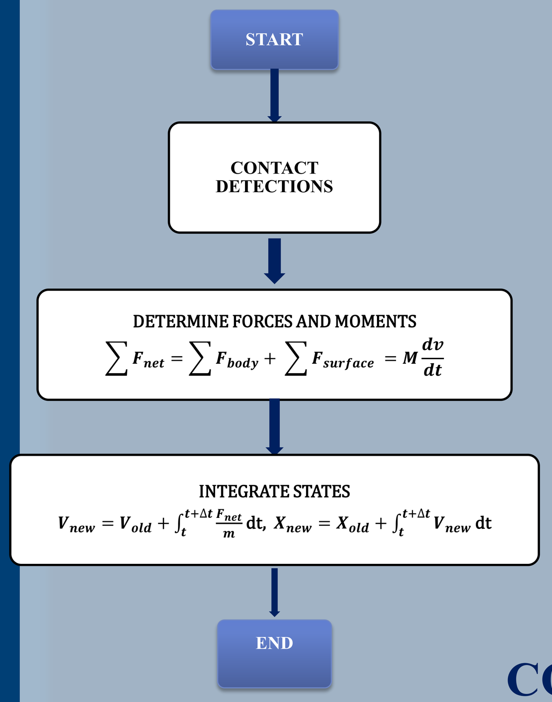
OBJECTIVES

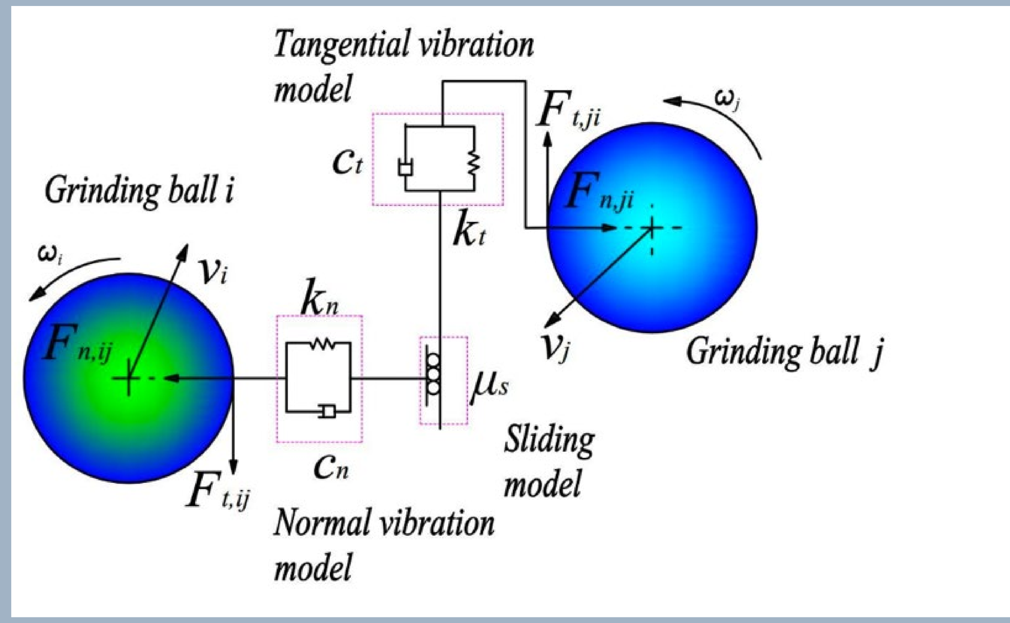
- ❖ Study stress distribution in the mill at different operational conditions.
- ❖ Develop a particle breakage probability function based on von mises stress criteria and frictional shear work.
- ❖ Quantify the breakage probability as the particle size distribution in the mill changes.

METHOD

DISCRETE ELEMENT METHOD (DEM)

DEM is a computational method that simulates the rotations, displacements, and contacts of discrete bodies/particles. This method can be used to study the motion of the charge (media and ore particles) in any comminution device. The method tracks the motion of each particle and models all particle-to-particle and particle-to-geometry collisions.





CONTACT MODEL

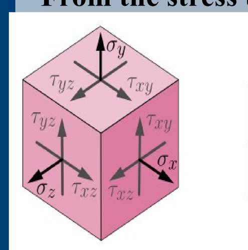
Normal Force $F_n = K_n S_n + C_n \dot{S}_n$ **Tangential Force** $F_\tau^T = min(|F_{\tau,e}^t|, \mu_s F_n^t)\dfrac{F_{\tau,e}^t}{F_{\tau,e}^t}$

K_n is the normal contact stiffness, defined previously for the linear hysteretic spring model in equation C_n is the normal damping coefficient, S_n is the contact normal overlap, $\dot{S}_n$ is the time derivative of the contact normal overlap

F_n^t is the contact normal force at time (t), μ_s is the friction coefficient.

VON MISES, MAXIMUM AND MINIMUM PRINCIPAL STRESES

From the stress tensor



$$\begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{xy} & \sigma_y & \tau_{yz} \\ \tau_{xz} & \tau_{yz} & \sigma_z \end{bmatrix}$$

$$I_1 = \sigma_{XX} + \sigma_{YY} + \sigma_{ZZ}$$

$$I_2 = \sigma_{XX}\sigma_{YY} + \sigma_{YY}\sigma_{ZZ} + \sigma_{XX}\sigma_{ZZ} - \sigma_{XY}^2 - \sigma_{YZ}^2 - \sigma_{ZX}^2$$

$$\sigma_{max} = \frac{I_1}{3} + \sqrt{\frac{I_1^2 - 3I_2}{3}} \qquad \sigma_{min} = \frac{I_1}{3} - \sqrt{\frac{I_1^2 - 3I_2}{3}}$$

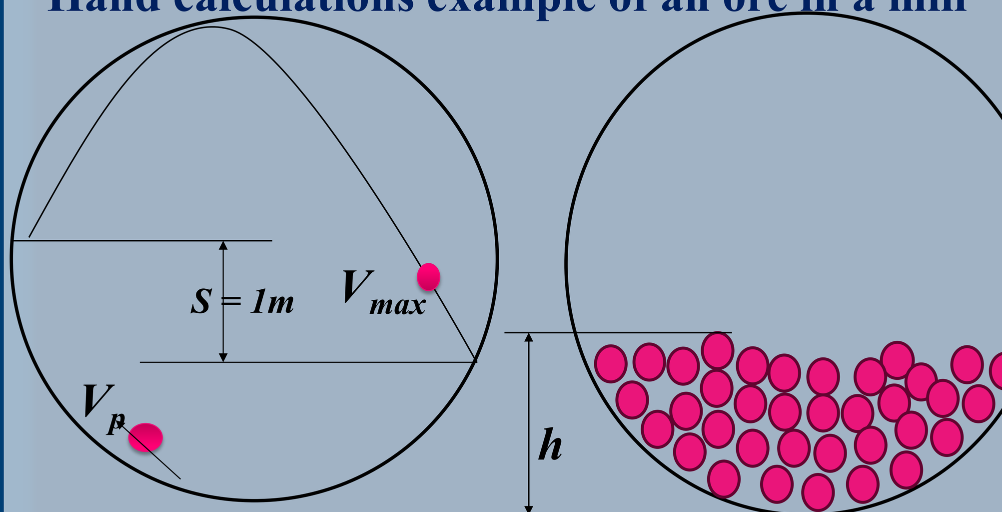
$$\sigma_v = \sqrt{\frac{1}{2}}\left[(\sigma_{XX} - \sigma_{YY})^2 + (\sigma_{YY} - \sigma_{ZZ})^2 + (\sigma_{ZZ} - \sigma_{XX})^2 + 6(\sigma_{XY}^2 + \sigma_{YZ}^2 + \sigma_{ZX}^2)\right]$$

Parameter	Symbol	Value
Mill Diameter	D_{Mill}	1.8m
Mill Speed	ω_{Mill}	22 RPM
Mill Filling	f	40%
Particle size	X	+32mm-50 mm
Particle density	r	3000kg/m³
Gravity	g	9.81 m/s²
Particle strength	σ_T	10MPa (tensile strength)

Ball mill

RESULTS AND DISCUSSIONS

Hand calculations example of an ore in a mill



$$V_p = \frac{\pi D_{mill}\omega_{mill}}{60} = 2\ \text{m/s}$$

$$V_{max} = \sqrt{(V_p^2 + 2gs)} = 5\ \text{m/s}$$

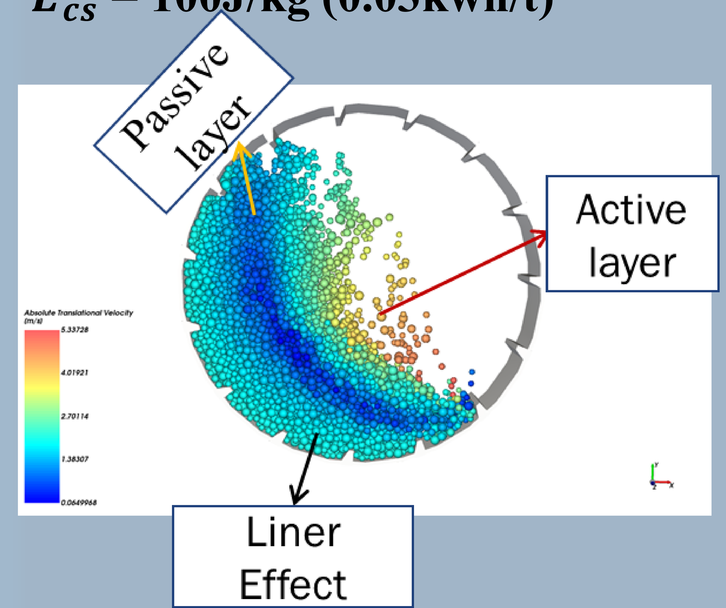
$$P_{max} = \rho g h = \rho g f D_{mill} \approx 12\text{-}22\text{kpa}$$

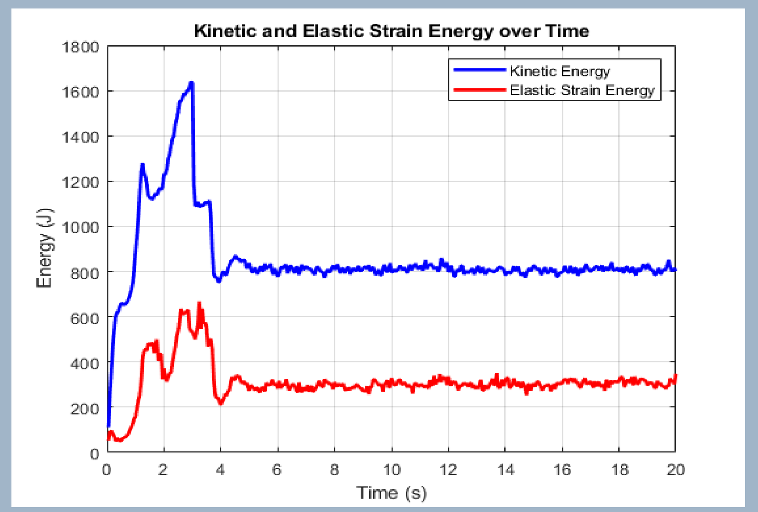
Specific comminution energy(E_{cs}) $= 0.5mV_{max}^2$ = 12.5J/Kg = 0.0035kwh/t

Considering a full-size mill of diameter 12m,

V_p = 5.3 m/s, V_{max} = 14 mls, $P_{max} \approx 85 - 140$kpa

E_{cs} = 100J/kg (0.03kwh/t)



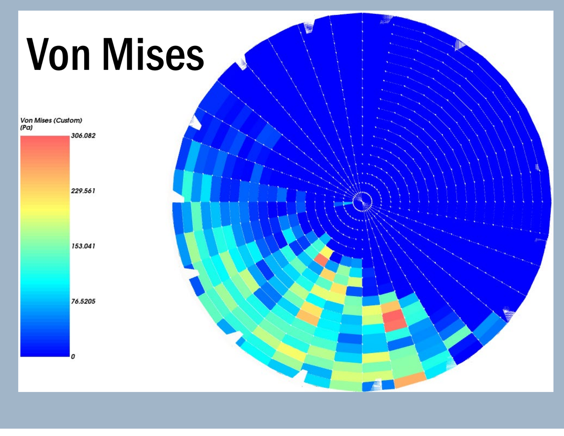


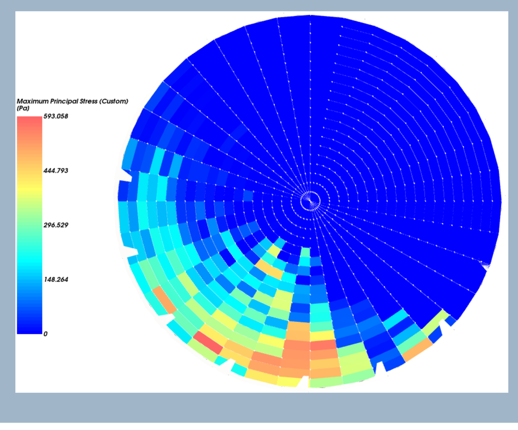
Specific energy in the mill 1100J/530kg = 2.075J/Kg = 0.000576kwh/t

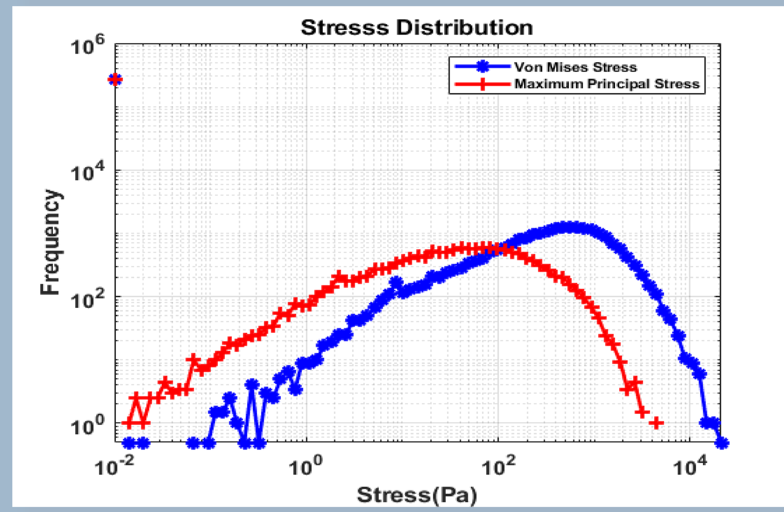
Kinetic energy = 800J

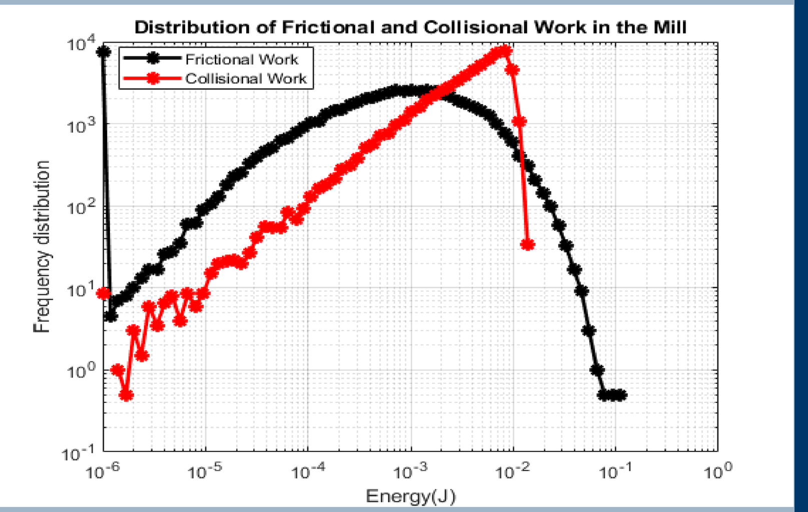
Elastic strain Energy =300J

STRESS DISTRIBUTION IN THE MILL









CONCLUSION

This study demonstrates that particles are more likely to break due to grinding within the bulk of the flow, rather than from impact at the surface of the charge. The velocity profile across the charge reveals the coexistence of active and passive regions, which influence potential breakage patterns. The active regions primarily drive surface impacts, while the passive regions are dominated by frictional forces from grinding within the charge. DEM simulation results support hand calculation predictions, indicating that breakage is unlikely to occur through impact. Instead, we propose that the stress conditions within the mill are the key drivers of particle breakage.

FUTURE WORK

More research will be conducted to calculate the stresses and frictional shear work in the mill:

- As the mill content changes.
- At various operational speed.
- At various mill filling rate

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