Efficient Fossil Energy Technologies Engineering Doctorate (EngD) Centre

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Population Balance Method Simulation of Biomass Pellet Milling in Pulverised Fuel Combustion Systems

Turning pellets

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in to particles

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In collaboration with the industrial sponsor:

Biomass and Fossil Fuel Research Alliance BF2RA

Outline

- Research Objectives
- Scenario for Simulation
- Simulation Development
- Analysis
- Future Work

Research Objectives

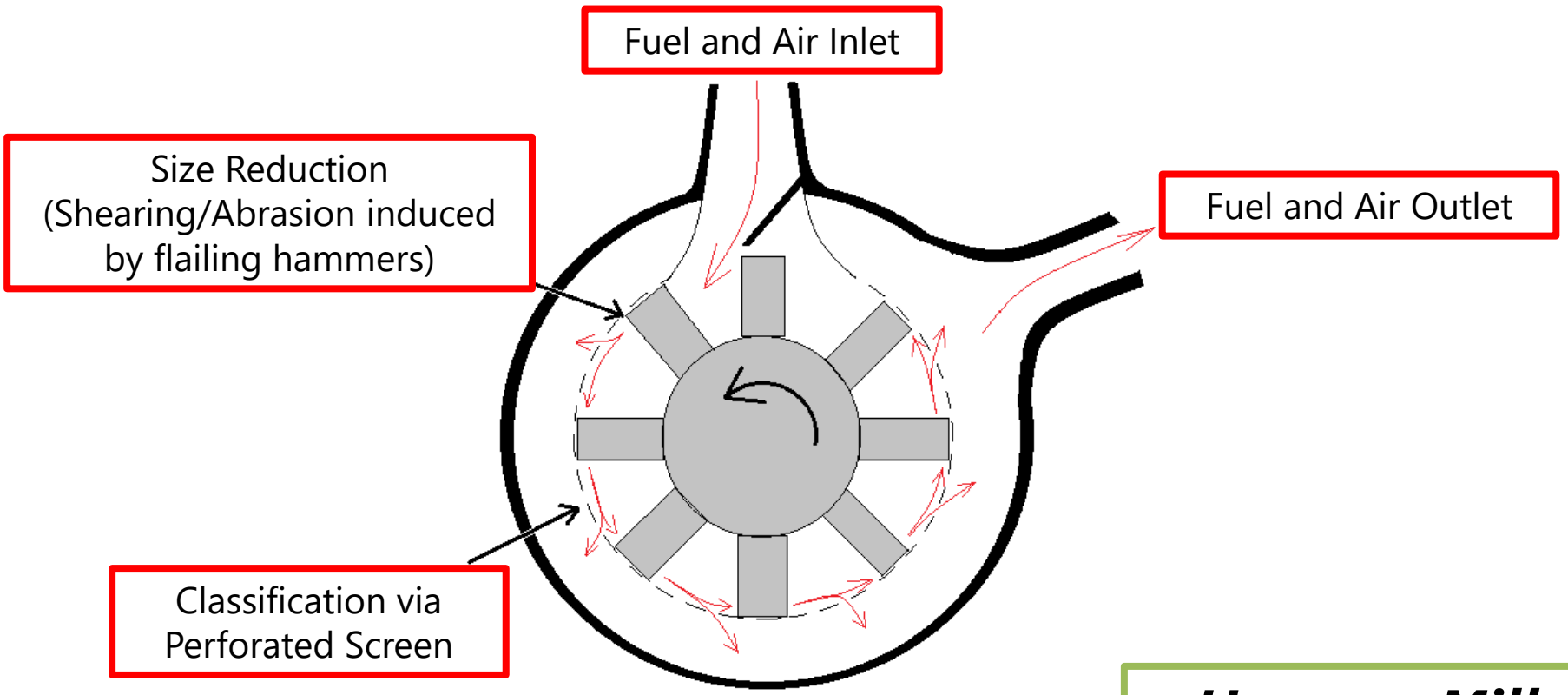
Working in conjunction with the sister project to develop:

- Fast processing simulation for biomass pellet milling
- Required output:
  - particle size distribution (PSD),
  - energy consumption,
  - mass throughput
- Aid decisions for biomass fuel choices by generators

Sister project PhD thesis by Dr. Orla Williams, "On Biomass Milling for Power Generation", available online at http://eprints.nottingham.ac.uk/33464/

Scenario for Simulation:

Mills and Mill Features

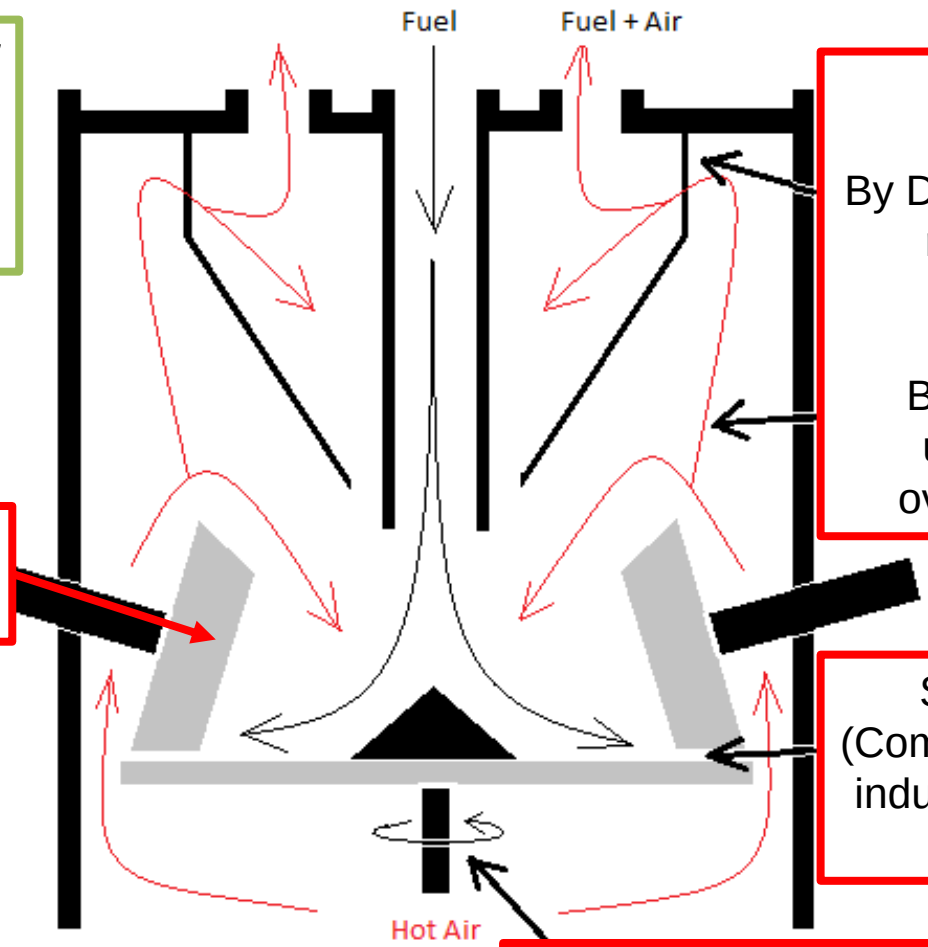


Hammer Mill Representation

Scenario for Simulation:

Mills and Mill Features

Lupolco Ring and Roller Mill Representation



Classification,

By Dynamic Classifiers reject oversize particles

By Elutriating Air unable to carry oversize particles

Pressure loading rollers

Size Reduction (Compression/Abrasion induced by rollers and table)

Rotating Bed Table

Simulation Development:

Population Balance Equation

Selection Function

Classification Function

Birth rate from other size classes

$$\frac{df(x,t)}{dt} = \alpha(f_0(x)) - c(x)f(x,t) - s(x)f(x,t) + \int_x^\infty b(x,y)s(y)f(y,t)dy$$

Feed function

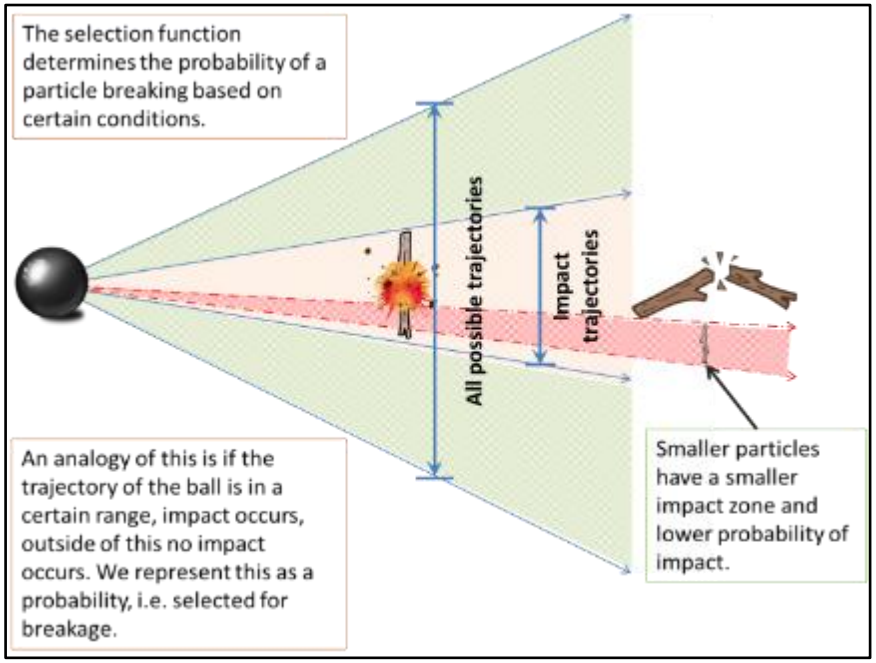
Death rate from the current class

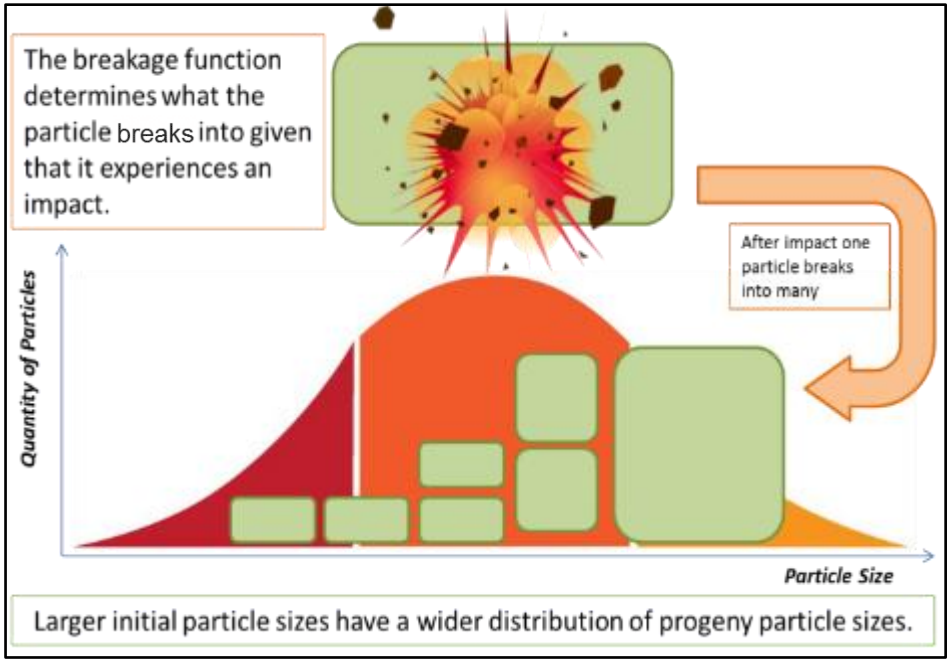
Breakage Function

- Conservation of properties (e.g. mass, volume, energy etc.)
- Governed by probabilistic functions, the selection and breakage functions, to determine the outcome
- Iterated to achieve steady-state operation
- Fast computational execution

Simulation Development:

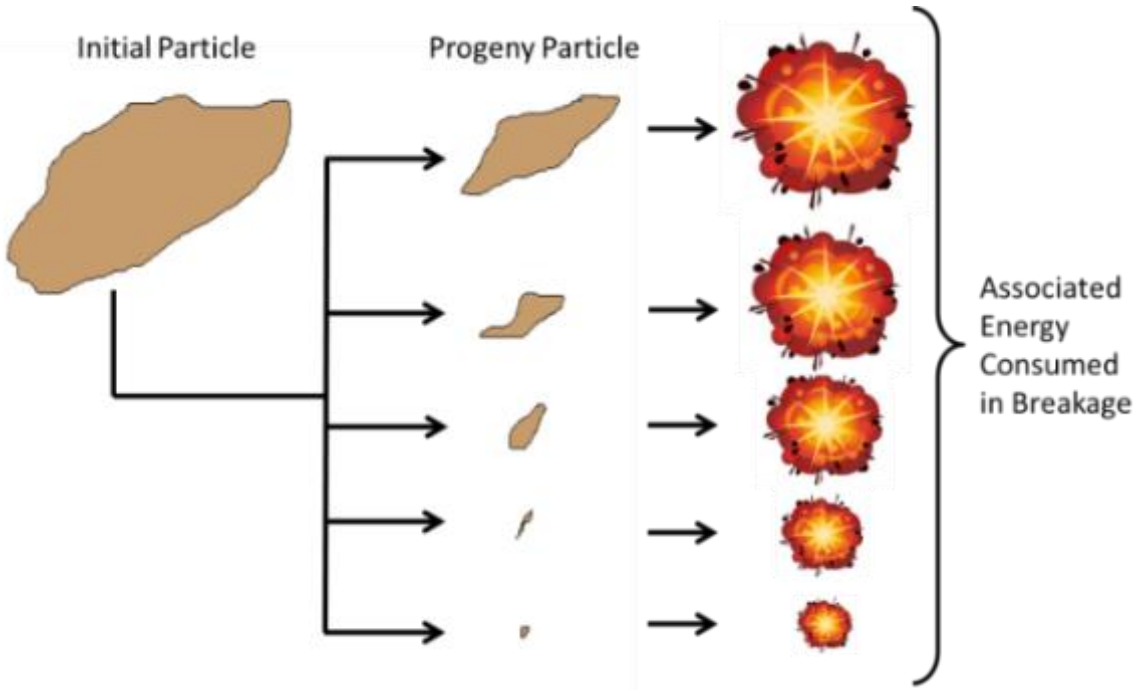
Selection and Breakage





Simulation Development:

Energy Coupling Model



$$E_{i,j} = E_{Mat}\left(\frac{1}{x_j - x_i}\right),$$

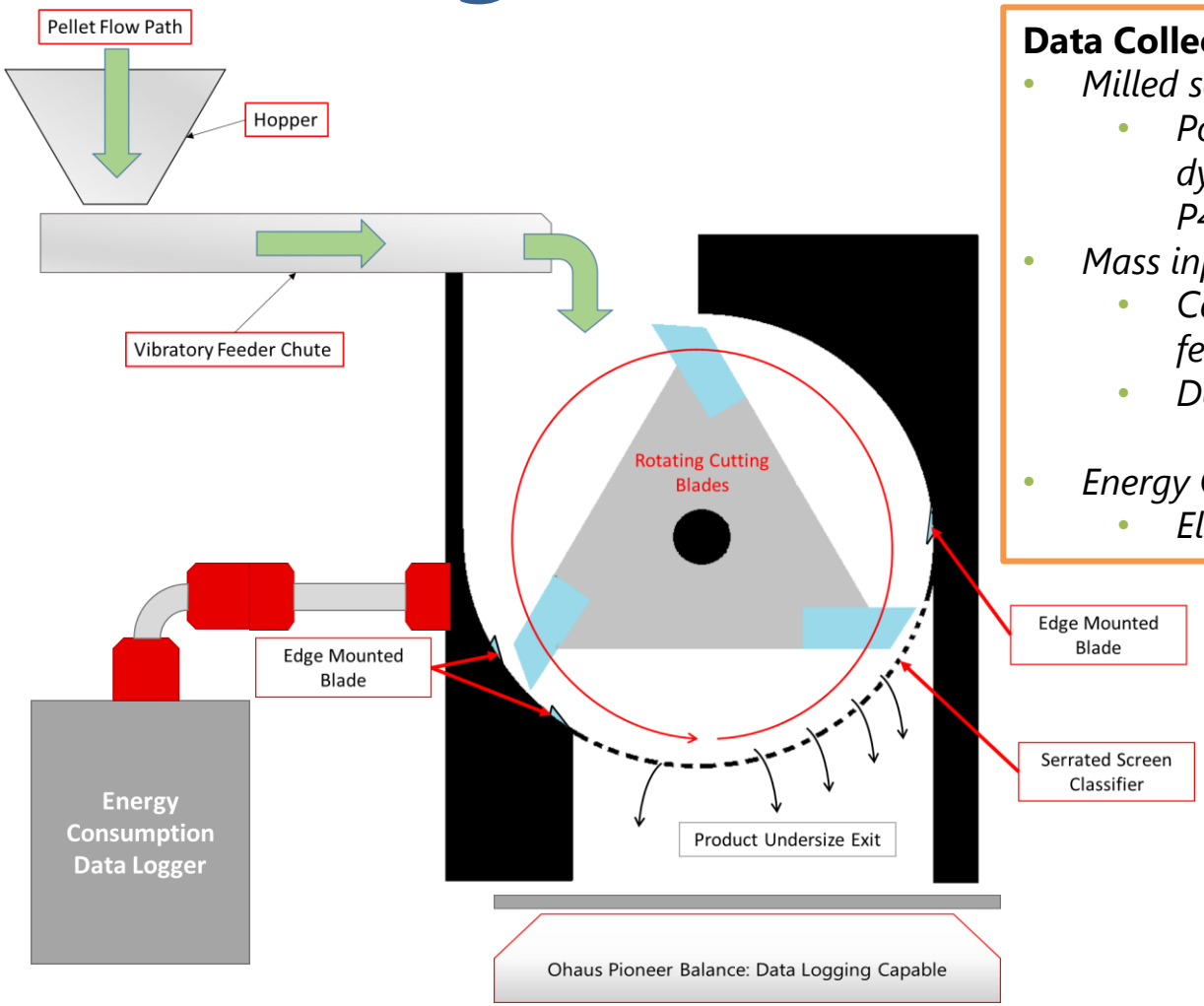
$$where\ \ x_j > x_i$$

$$E_{Mat}: material\ constant$$

- Steady-state energy consumption determined quantity of size reduction in any time period
- Energy consumption is also subject to individual materials
- Model is dependent on the selection function and a material constant

Experimental Data:

Cutting Mill – Retsch SM300



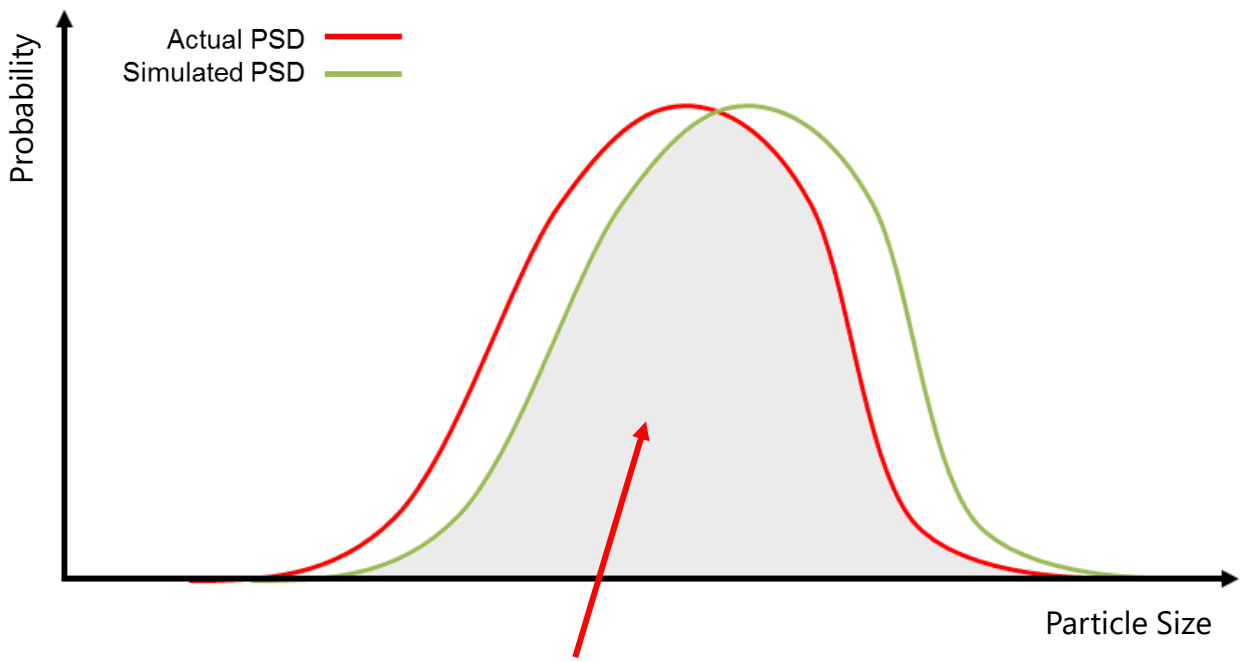
Data Collected:

- *Milled sample for PSD analysis*
  - *Post experiment sieving and dynamic image analysis (Camsizer P4)*
- *Mass input/output flow rates:*
  - *Calculated from known mass and feeder timing*
  - *Data logging balance tracking*
- *Energy Consumption by mill*
  - *Elcomponent SPC Pro data logging*

Note: *Data from the sister project and supplemented with additional experiments are used to develop the model*

Simulation Analysis:

Modelling Fitting and Analysis

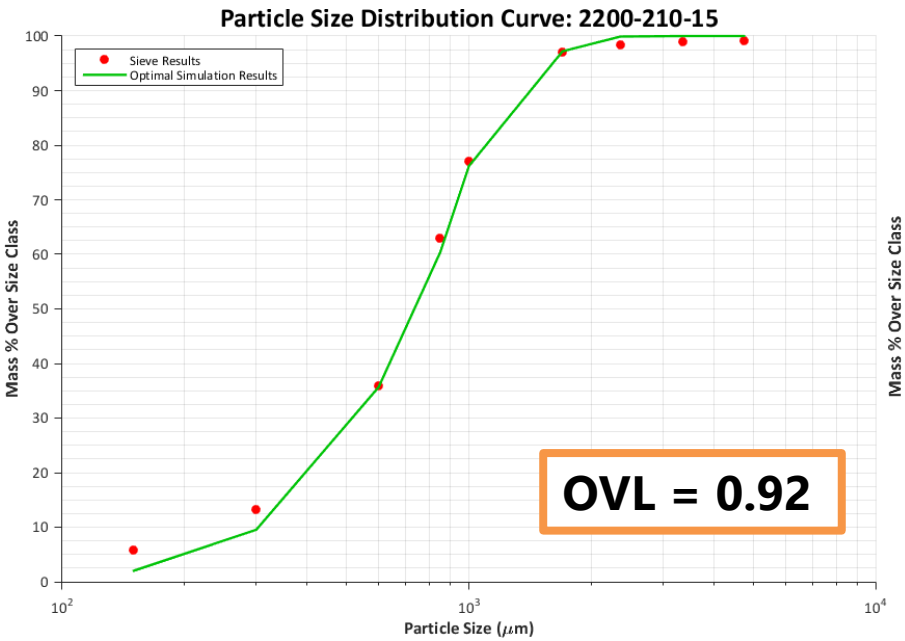


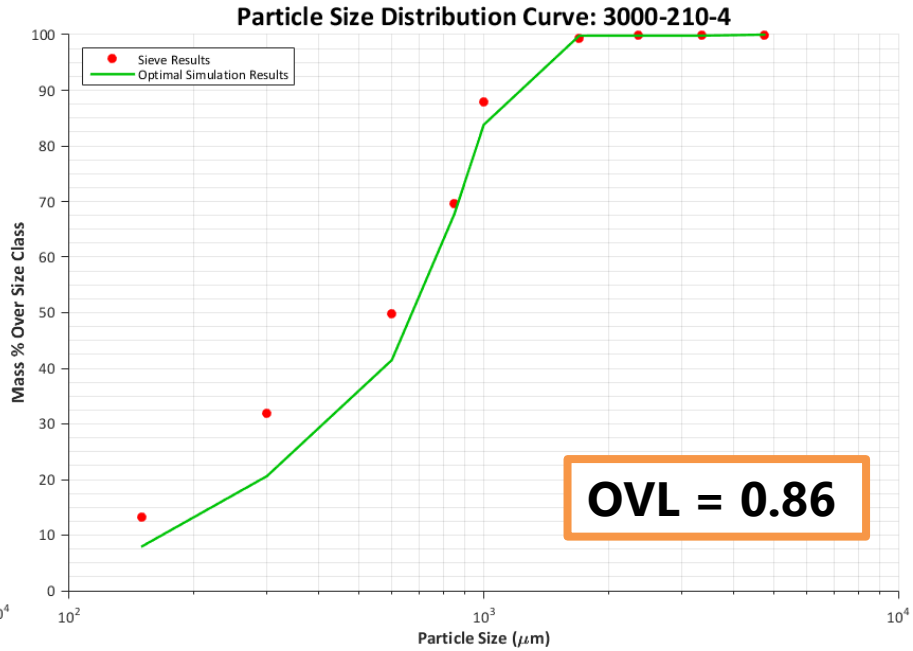
$$OVL = \int_0^{\infty} \min_x \{Actual, Simulated\}\, dx$$

- **Optimisation:** Constrained non-linear optimisation using an 'interior-point' algorithm
- **Overlapping co-efficient (OVL):** A measure for quantifying fit and objective function for optimisation based on the Probability Density Function of the PSD

Simulation Analysis:

Modelling Fitting





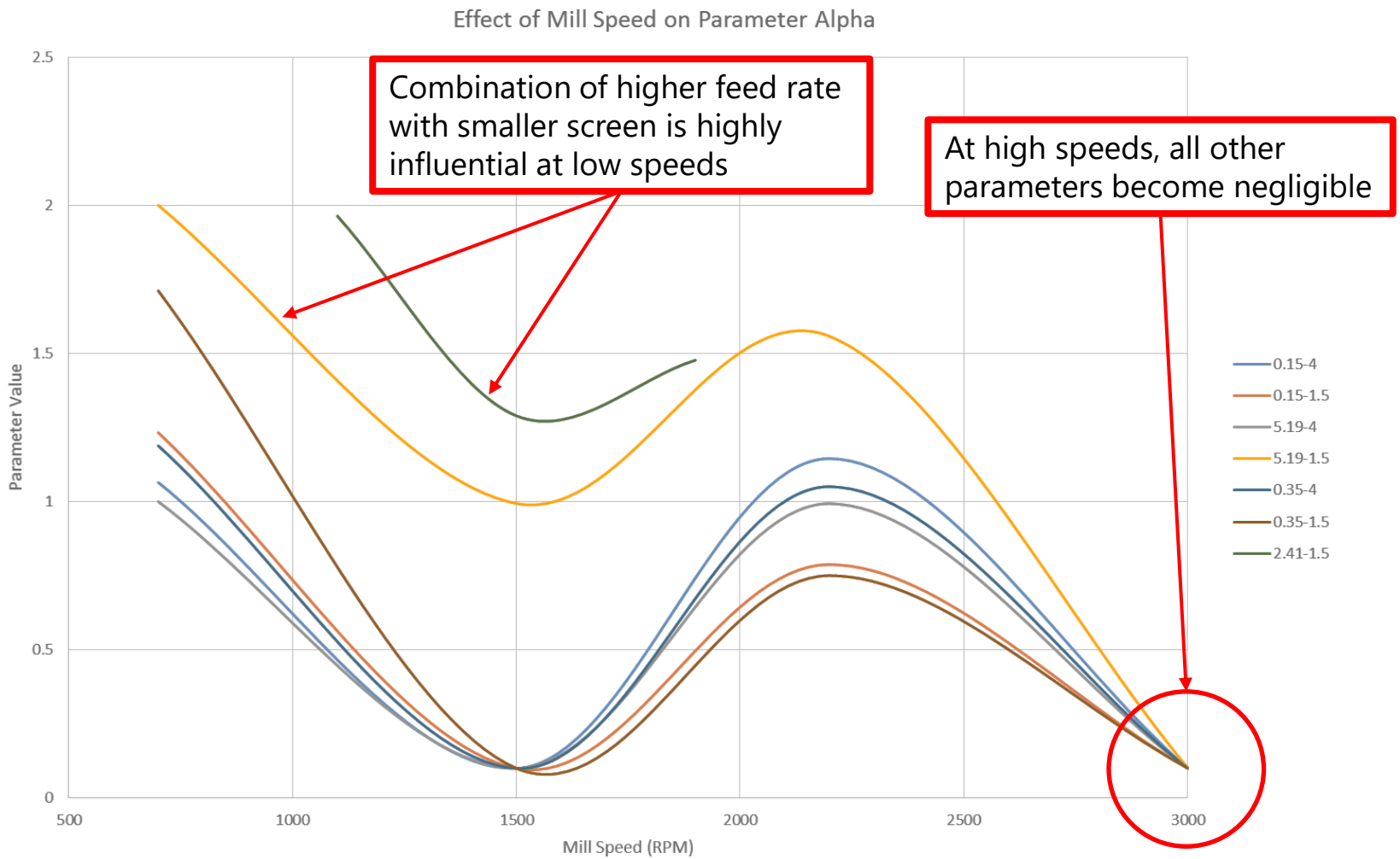
Model is trained to a minimum OVL = 0.86 with a preferential selection and breakage functions:

$$s_i = \left(\frac{x_i}{x_0}\right)^{\alpha} \quad \& \quad b_{i,j} = 1 - e^{-\left(\frac{x_i}{\gamma x_j}\right)^{\beta}}$$

x_i	- Initial particle size	x_0	- Largest particle size
x_j	- Particle of size $> x_i$	α, β, γ	- Fitted Parameter Values

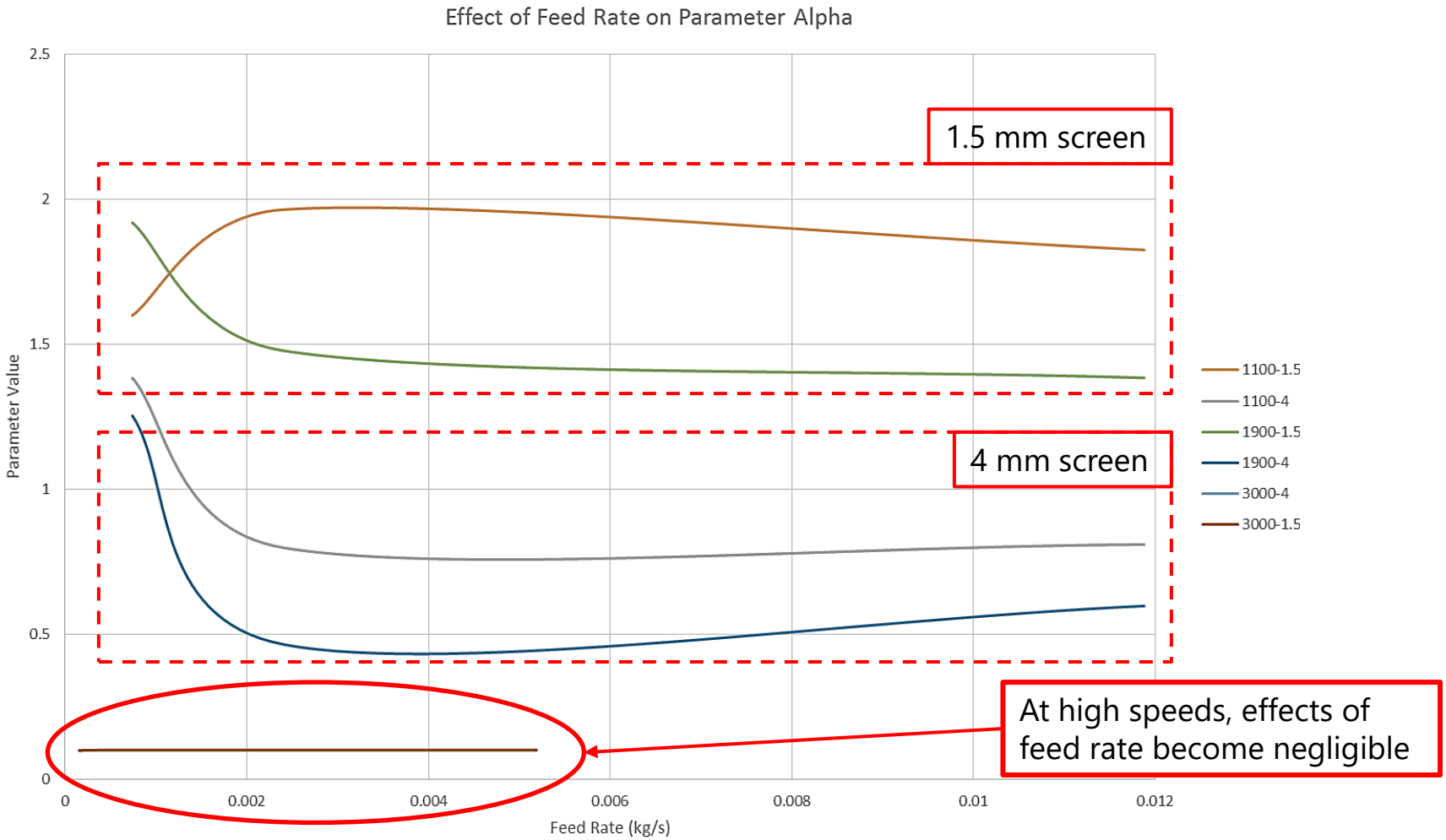
Simulation Analysis: Parameter Variation I

Effect of Mill Speed on Parameter α



Simulation Analysis: Parameter Variation II

Effect of Feed Rate on Parameter α



Simulation Analysis:

Key Summary Conclusions

- Model is optimising parameters in a manner that reflects mill operation such as:
  - Smaller mill screen size results in narrower spread of particle sizes
  - Feed rate has a greater effect when screen size is small
  - As mill speed increases, influence from other variables diminishes
- Complex yet distinctive relationships identified in the analysis of optimised parameters
- Most influential milling variable on the parameters is screen aperture when mill speeds are low
- Milling energy requires a more quantitative correlation with pellet characteristics

Future Work:

Material Characterisation

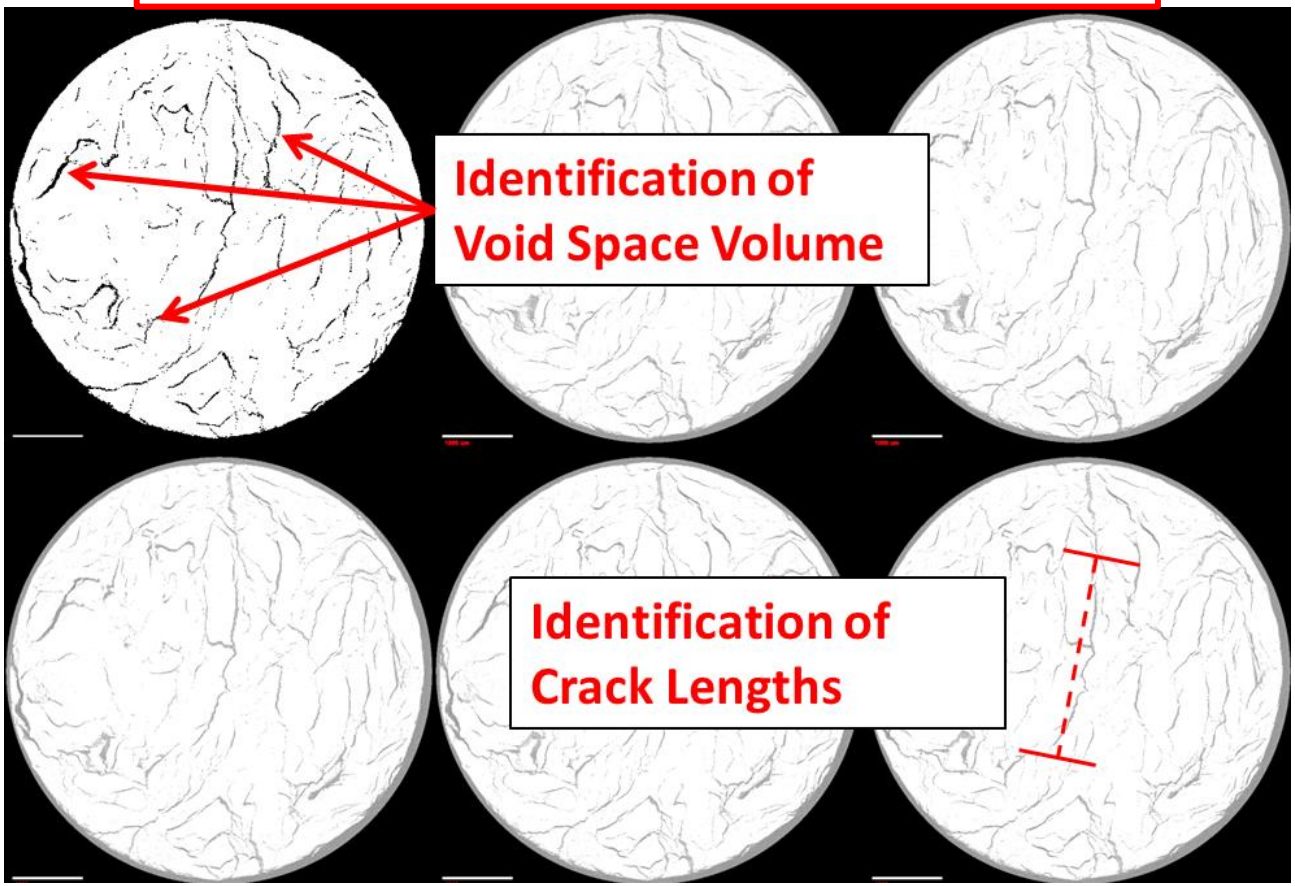
Objective:

Establish a relationship between pellet characteristics and its potential for grinding with energy required to achieve its comminution

Challenges:

- Pellet making processes vary
- Use of binders varies

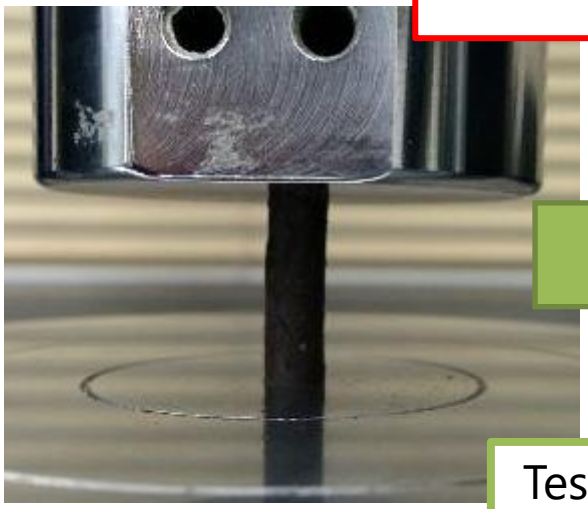
Computerised Tomography



Future Work:

Material Characterisation

Compressive/Shear Strength Testing

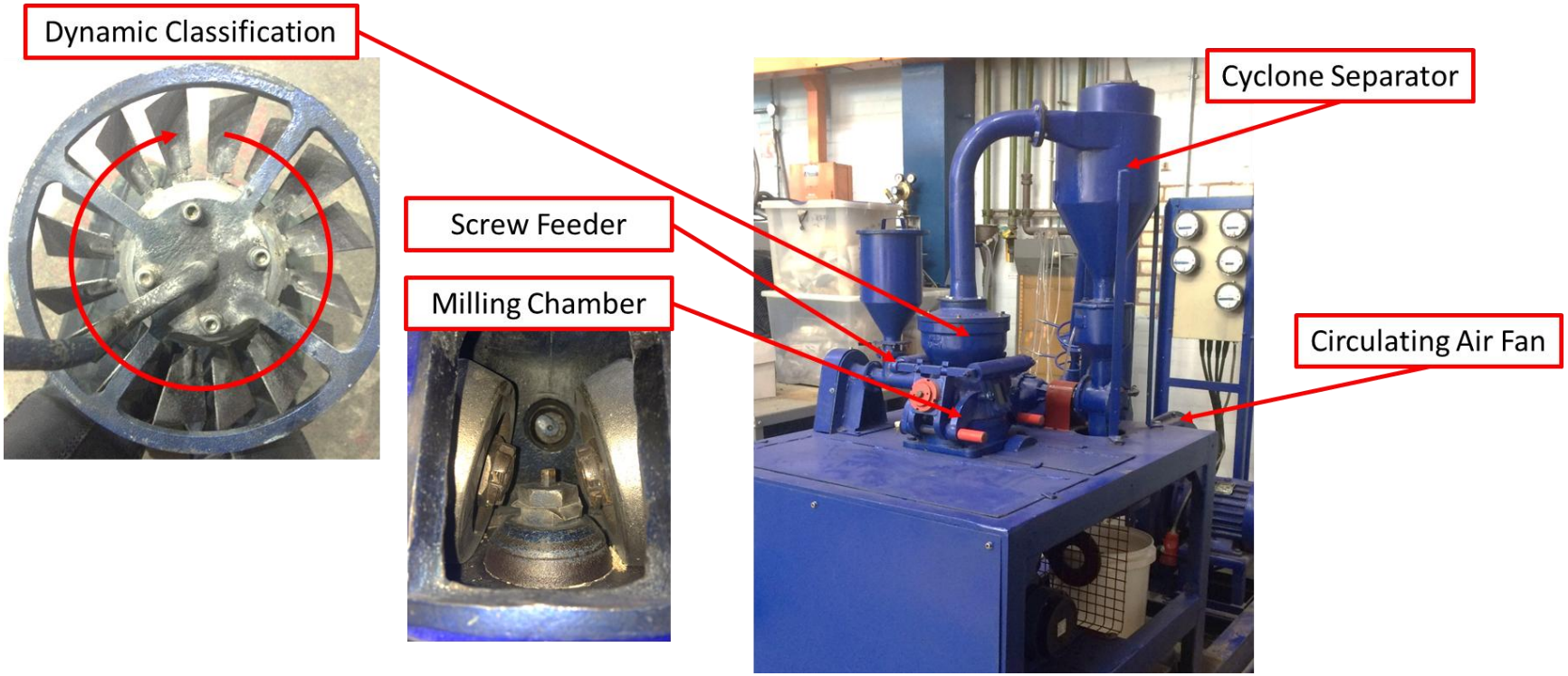


Testing to a correlation between CT results for void space and crack lengths with compressive and shear strength results

Note: *As part of the sister project experiments of this type were completed however never correlated to other specific characteristics of the pellet, which is the aim of this line of investigation*

Future Work:

Lupolco Ring and Roller Mill



Objective: test performance of the model on a different style mill

Further Still: Hand off for industrial partners implementation and assessment

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Thank you

If you have any questions please feel free to contact me:

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Key References

1. Kumar, S. and D. Ramkrishna, *On the solution of population balance equations by discretization—I. A fixed pivot technique.* Chemical Engineering Science, 1996. **51**(8): p. 1311-1332.

2. Otwinowski, H., *Energy and population balances in comminution process modelling based on the informational entropy.* Powder Technology, 2006. **167**(1): p. 33-44.

3. Williams, O., *On biomass milling for power generation*. 2016, University of Nottingham.

4. Williams, O., et al., *Influence of mill type on densified biomass comminution.* Applied Energy, 2016. **182**: p. 219-231.

5. Gil, M. and I. Arauzo, *Hammer mill operating and biomass physical conditions effects on particle size distribution of solid pulverized biofuels.* Fuel Processing Technology, 2014. **127**: p. 80-87.

6. Austin, L.G., R.R. Klimpel, and P.T. Luckie, *Process engineering of size reduction: ball milling*. 1984: Society of Mining Engineers of the American Institute of Mining, Metallurgical and Petroleum Engineers.

Work Space