Principles of Mechanical Crushing
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  - Construction Crusher and Screens, R&D Quality
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- Ph.D 2007, Chalmers University
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  - Modeling, simulation and optimization of crushing plants
  - Technical-Economic Optimization
- Sandvik employee since 2004
- Road biker
- Home improvement projects
Crushing Chamber and Material Development

What we do

- Crushing Chambers
  - Design of the wear parts in the crusher
  - The part were the crushing is done
  - Determines crusher performance

- Material Technology
  - Wear parts, crushing chamber in manganese steel
  - Other parts, big casted parts
Crushing Chamber and Material Development

What we do

- Technical Calculations
  - FEA
  - Other analysis

- Hydraulics and Automation
  - Bearings and lubrication
  - Crushing Process Control System
Objective

Explain the interaction between Rock Material and Crusher
Take home messages

The Take Home Messages will address:
Trouble Shooting
Improve Yield
Improve Performance
Agenda

- Cone Crusher operating principals – Common view of the cone crusher
- Cone Crusher Modeling – What are the reasons for the crusher to performance as it does?
- Crusher Process – Operating the crusher in the process
- Conclusions
The Cone Crusher

- Why Cone Crusher?
- The cone crusher design concept is an effective and smart way of realizing compressive crushing
- Aggregate Production
- Mechanical Liberation of Valuable Minerals
Operating Principals

Material Flow

Opening Phase = Transport

Closing Phase = Crushing
Operating Principals

10 Indentations
Crushing Zones

Mantle

Concave

Crushing

Single Particle Breakage SPB

Inter Particle Breakage IPB
Operating Principals

Breakage Modes

- In a cone crusher the stones are crushed with both SPB and IPB as the material moves down through the chamber.
- The relative amounts of IPB and SPB depends on factors like chamber design, crusher geometry, speed, css, eccentric throw, and others.

<table>
<thead>
<tr>
<th></th>
<th>SPB</th>
<th>IPB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fines</td>
<td>Less</td>
<td>More</td>
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<tr>
<td>Shape</td>
<td>Flaky</td>
<td>Cubic</td>
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<td>Force</td>
<td>Low</td>
<td>High</td>
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</tbody>
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Operating Principals
Capacity
Cross section area

Area function

Choke level
Operating Principals

Capacity

\[ M_1 = M_2 = \ldots = M_{\text{choke}} = \ldots = M_n \]

\[ M_{\text{choke}} = V_{\text{choke}} \times \rho = \text{Capacity} \]

Choke zone

Choke level

Area \([\text{m}^2]\) vs. \(y\)-coordinate \([\text{m}]\)
Do you believe it?
All chambers have the same capacity.
Operating Principals

Nominal Geometry, CSS = 15

CH440 F

Nominal Geometry, CSS = 35

CH440 EC

Nominal Cross-Sectional Area

X-coordinate [m]

Y-coordinate [m]

Area [m²]
Crusher Modeling

Intro

Why speak about modeling?

Modeling has two purposes:
- Predict the performance of a process – Simulation software
- Knowledge on the process operating principals – Common language and understanding
Crusher Modeling

The Theory

\[ p_i = \left\{ \left[ B_i^{\text{inter}} S_i + (1 - S_i) \right] M_i^{\text{inter}} + B_i^{\text{single}} M_i^{\text{single}} \right\} p_{i-1} \]

\( \left( \frac{s}{b} \right)_{u_i} \) = Compression ratio
Crusher Modeling
Crusher Modeling

Open and Closed Area Function

Crushing Zones

Compression

High Compression = High Force
Crusher Modeling
Simulation results
Crusher Modeling
Simulation results
Crusher Modeling

The effect of eccentric throw

- ECC 18 mm
  - 28 zones
  - 189 tph

- ECC 32 mm
  - 20 zones
  - 328 tph

- ECC 48 mm
  - 14 zones
  - 437 tph
Crusher Modeling
The effect of eccentric throw

| ECC 18 mm | 189 tph | 4-25 mm: 161 tph, 85 % | 0-4 mm: 24 tph, 13% |
| ECC 32 mm | 369 tph | 4-25 mm: 256 tph, 78 % | 0-4 mm: 42 tph, 13% |
| ECC 48 mm | 437 tph | 4-25 mm: 304 tph, 70 % | 0-4 mm: 48 tph, 11% |

Crusher CSS not optimized!
Crusher Modeling

The effect of eccentric throw

ECC 18 mm

ECC 32 mm

ECC 48 mm

Take home message:

Inter Particle Breakage increases with Eccentric Throw

(the effect is stronger at smaller throws)
Crusher Modeling

Results from field test

Take home message:
Inter Particle Breakage yields better shape
Crusher Modeling

Results from field test

Take home message:

Inter Particle Breakage produces fines
Crusher Modeling

The effect of speed

210 rpm
10 zones

290 rpm (org)
15 zones

430 rpm
28 zones
Crusher Modeling

The effect of speed, production of 4-25 mm

210 rpm
426 tph
4-25 mm: 250 tph, 59%
0-4 mm: 29 tph, 7%

290 rpm (org)
369 tph
4-25 mm: 264 tph, 72%
0-4 mm: 43 tph, 12%

430 rpm
272 tph
4-25 mm: 211 tph, 78%
0-4 mm: 46 tph, 17%

All on CSS 20 mm. CSS should be optimized for each setting
Crusher Modeling

The effect of speed, production of 4-25 mm

- 210 rpm
- 290 rpm (org)
- 430 rpm

Take home message:
Inter Particle Breakage increases with Speed
(the effect is stronger at lower speeds)

All on CSS 20 mm. CSS should be optimized for each setting
Crusher Modeling

Inter Particle Breakage

Take home message:
The limit of the amount of Inter Particle Breakage is well in reach within a Cone Crusher.
Crusher Modeling

Inter Particle Breakage, Worst and Best Case

Worst Case:
- Small Throw
- Low Speed
- Large CSS

Best Case:
- Large Throw
- High Speed
- Medium CSS

64 % IPB

Take home message:
Inter Particle Breakage is the dominant breakage mode in a cone crushe.
Crusher Modeling

The effect of chamber geometry

Fine

Medium Coarse

Extra Coarse

Wear, IPB, Forces, Reduction
Crusher Modeling

Crushing Force

Single Particle Breakage (SPB)

Inter Particle Breakage (IPB)

Crushing Force

\[ F \]

\[ b \]

\[ s \]
Crusher Modeling
Inter Particle Breakage Force

\[ F = f(s/b, \sigma) \]

- \( b \): Bed height
- \( s \): Compression
- \( s/b \): Compression ratio
- \( F \): Force
- \( \sigma \): Fraction length

\[ \sigma_k = \text{size distribution width} \]

Take home message:
Inter Particle breakage
Longer fractions results in higher crushing pressure
Crusher Modeling
Single Particle Breakage Force

Take home message:
Single Particle Breakage requires lower crushing force compared to Inter Particle Breakage.

b: Rock height
s: compression
s/b: compression ratio
The Crushing Process

Why not always use a big throw?

Design capacity: 200 tph
Crusher Capacity: 300 tph
Choke fed Crusher operation (300 tph):
Material in surge bin runs out at even intervals
Consequence:
Crusher is operated choke fed 66% of total operating time feeding the screen with 300 tph
Screen overload
Solution: Adjust throw in order to reach 200 tph capacity
Improvement in fines production
The Crushing Process
Optimizing Particle Shape

Relation between CSS and Shape
• The size where the best shape can be found is at CSS
• It is very difficult for cubical stones larger than CSS to pass the chamber
• Breakage of stones creates flaky particles. Smaller flaky stones will more easily find their way through the chamber

Take home message:
Best Shape is found at the same size as CSS
The Crushing Process
Optimizing Particle Shape

Relation between Feed size and Shape

• The greater reduction ratio the worse particle shape.
• Inter particle breakage improves shape. When crushing a bed of material weaker particles will break first. Flaky or elongated particles are weaker then round.
• Breaking round particles gives flaky material.

Take home message:
The Particle Shape can be improved by moving the reduction to earlier stages in the plant.
The Crushing Process
Optimizing Particle Shape
Take home messages:

Capacity is determined by the choke area

Inter Particle Breakage:
Is the dominant breakage mode in a cone crusher
Increases with Eccentric Throw
Increases with Speed

Longer fractions results in higher crushing pressure
The limit of the amount of Inter Particle Breakage is well in reach within a Cone Crusher.
Take home messages:

Single Particle Breakage requires lower crushing force compared to Inter Particle Breakage.
Process Capacity and Crusher Capacity must correspond
Best Shape is found at the same size as CSS
The Particle Shape can be improved by moving the reduction to earlier stages in the plant
Questions?
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