QUARRY ACADEMY

Improving Processes. Instilling Expertise.

DYNO
Dyno Nobel

SANDVIK
Getting Control
Alex Scott

QUARRY ACADEMY

Improving Processes. Instilling Expertise.
Lecture Overview

- A look at some of the issues which in the day to day operation influence crusher performance

- A look at some possible problems, trouble shooting tips and improvements.
Our journey

- A look at material properties and their influence on equipment performance

- A look at the machine factors influencing equipment performance

- A look at some negative factors reducing equipment performance.

- A look at some take home messages which might improve performance.
Raw Material
Species of rock

- **IGNEOUS**
  - **Surface** - Fine grained
    - Basalt
  - **Intrusive** - Medium grained
    - Diabase
  - **Deep** - Coarse grained
    - Gabbro
Raw Material
Species of rock

- **METAMORPHIC**
  ROCK TRANSFORMED IN THE EARTH´S CRUST DUE TO INCREASED PRESSURE AND TEMPERATURE

![Limestone](image1.jpg)  ![Marble](image2.jpg)

![Granite](image3.jpg)  ![Gneiss](image4.jpg)
Raw Material
Species of rock

- SEDIMENTARY

Take Home Message
The grain structure of the raw material has an influence on the final shape of the finished product and the power and/or pressure pulled by the crusher.
### Sandvik Test Methods

**Impact Work index, \( W_i \)**

<table>
<thead>
<tr>
<th>Impact Work Index (WI)</th>
<th>Description of the Crushability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10</td>
<td>Very soft</td>
</tr>
<tr>
<td>10 – 14</td>
<td>Soft</td>
</tr>
<tr>
<td>14 – 18</td>
<td>Medium</td>
</tr>
<tr>
<td>18 – 22</td>
<td>TOUGH</td>
</tr>
<tr>
<td>22 – 26</td>
<td>Very TOUGH</td>
</tr>
<tr>
<td>&gt; 26</td>
<td>Extremely TOUGH</td>
</tr>
</tbody>
</table>
### Sandvik Test Methods

#### Abrasion Index, AI

<table>
<thead>
<tr>
<th>Abrasion Index (AI)</th>
<th>Description of the Wear</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.1</td>
<td>Very low wear</td>
</tr>
<tr>
<td>0.1 – 0.2</td>
<td>Low wear</td>
</tr>
<tr>
<td>0.2 – 0.4</td>
<td>Intermediate wear</td>
</tr>
<tr>
<td>0.4 – 0.6</td>
<td>Normal medium wear</td>
</tr>
<tr>
<td>0.6 – 0.8</td>
<td>High wear</td>
</tr>
<tr>
<td>&gt; 0.8</td>
<td>Extremely high wear</td>
</tr>
</tbody>
</table>

[Image of abrasion test apparatus and wear samples]
# Sandvik Test Methods

Rawmaterial Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>WI</th>
<th>AI</th>
<th>Compressive strength (lbs/in²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphibolites</td>
<td>16</td>
<td>0.4</td>
<td>29000 - 43500</td>
</tr>
<tr>
<td>Andesite</td>
<td>16</td>
<td>0.5</td>
<td>24650 - 43500</td>
</tr>
<tr>
<td>Basalt</td>
<td>20</td>
<td>0.25</td>
<td>43500 - 58000</td>
</tr>
<tr>
<td>Diabase</td>
<td>18</td>
<td>0.28</td>
<td>36250 - 50750</td>
</tr>
<tr>
<td>Dolomite</td>
<td>12</td>
<td>&lt; 0.02</td>
<td>7250 - 21750</td>
</tr>
<tr>
<td>Diorite</td>
<td>19</td>
<td>0.4</td>
<td>24650 - 43500</td>
</tr>
<tr>
<td>Gabbro</td>
<td>21</td>
<td>0.4</td>
<td>29000 - 50750</td>
</tr>
<tr>
<td>Greywacke</td>
<td>18</td>
<td>0.3</td>
<td>21750 - 43500</td>
</tr>
</tbody>
</table>
## Sandvik Test Methods
### Rawmaterial Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>WI</th>
<th>Al</th>
<th>Compressive strength (lbs/in²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gneiss</td>
<td>16</td>
<td>0.48</td>
<td>29000 - 43500</td>
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<tr>
<td>Granite</td>
<td>16</td>
<td>0.46</td>
<td>29000 - 45000</td>
</tr>
<tr>
<td>Limestone</td>
<td>11</td>
<td>&lt; 0.01</td>
<td>11600 - 26100</td>
</tr>
<tr>
<td>Marble</td>
<td>12</td>
<td>&lt; 0.02</td>
<td>14500 - 29000</td>
</tr>
<tr>
<td>Quartzite</td>
<td>16</td>
<td>0.75</td>
<td>21750 - 43500</td>
</tr>
<tr>
<td>Sandstone</td>
<td>10</td>
<td>0.75</td>
<td>4350 - 21750</td>
</tr>
<tr>
<td>Iron ore (Hematite)</td>
<td>11</td>
<td>0.5</td>
<td>14500 - 29000</td>
</tr>
<tr>
<td>Iron ore (Magnetite)</td>
<td>8</td>
<td>0.2</td>
<td>7250 - 21750</td>
</tr>
</tbody>
</table>
FINAL PRODUCTS

- Size
  - Fraction Limits
  - Misplaced Particles
  - Size Distribution

- Shape
  - Flakiness
  - Elongation

- Surface
  - Crushed Surface
FINAL PRODUCTS
Misplaced particles

ASTM D 448-86, 1988

Misplaced Particles 10/15
✓ Oversize: 10%
✓ Undersize: 15%

Fraction 1" x 2":

1"

Undersize

Oversize

2"
FINAL PRODUCTS
Curve limitations

Sand limits

- ASTM 1
- ASTM 2
- Euronorm 1
- Euronorm 2
FINAL PRODUCTS
Particle shape

- Flakiness (length/thickness)
- Elongation (length/width)
- Flat (thickness/width)

ASTM D 4791
PARTICLE SHAPE

- ASTM
  - ✓ Flat (W/T ratio)
  - ✓ Elongated (W/L ratio)
- Ratio varies 1:2, 1:3, 1:4, 1:5
Crushers & crushing
A look at crushers and the mechanical and process material influences

Crushing

Pressure
Jaw crusher
Gyratory crusher
Cone crusher
Roll crusher
Sizer

Impact
Impact breaker
Hammer mill
Ball mill
Rod mill
Compression Breakage

Stone on metal

Simple loading
More angular particles

Stone on stone

Complex loading
More cubical particles
Cone crusher

Operation
Eccentric Motion
Impact

The stone is subjected to many random hits

Autogenous crushing

Details of a vertical impact crusher

The result is often a more cubical product with higher amount of fines.
Impactor Operation
VSI How It Works

Rotor Only Feed
VSI How It Works

Rotor And Bi-Flow Feed
What do we really know about crushing?

- What are the major influences?
- From material factors?
- From equipment/mechanical factors?
What are we about to examine?

- The major influences on crusher performance, which are
  
  - material factors such as
    1. toughness,
    2. bulk density
    3. feed size analysis
  
  - machinery factors such as
    1. setting
    2. throw (cone crushers)
    3. chamber volume
    4. speed
Mechanical & material

Limestone

1” – 3”

Limestone

1” – 3”

0 – 1¼”

0 – 1¼”

The same energy is used.
Material

Limestone

1” – 3”

0 – 1 1/4”

Basalt

1” – 3”

0 – 1 1/4”

Toughness is a major factor
Mechanical

Volume by throw, chamber profile or material bulk density & feed grading are factors.
Mechanical

Basalt

1” – 3”

0 – 1\(\frac{1}{4}\)”

Basalt

1” – 5”

0 – 1\(\frac{1}{4}\)”

Reduction ratio-CSS is a factor
Basic Crushing and Screening Concepts
Reduction Ratio (1)

$$\text{Reduction Ratio} = \frac{F_{80}}{P_{80}}$$

$F_{80} = (80 \% \text{ of feed mtrl})$

$P_{80} = (80 \% \text{ of the product})$
Basic Crushing Concepts

Reduction Ratio

<table>
<thead>
<tr>
<th>Typical reduction:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jaw crusher</td>
</tr>
<tr>
<td>Gyratory crusher</td>
</tr>
<tr>
<td>Cone crusher</td>
</tr>
<tr>
<td>Impact crusher (VSI)</td>
</tr>
<tr>
<td>Impact crusher (HSI)</td>
</tr>
</tbody>
</table>

![Graph showing reduction ratios for different crushers](image-url)
Using reduction ratio to predict required no. of crushing stages

- 2-stage Impact Plant:
  10x7 = 70
  **OK**, Only for Ai <0.15

- 2-stage Jaw/cone Plant:
  P_{80} Feed: 16”
  P_{80} Products: 5/8”
  3x4 = 12
  **NOT OK**

- 3-stage Jaw/cone Plant:
  3x3x4 = 36
  **OK**

Min. required plant reduction:

\[
\frac{16}{\frac{5}{8}} = 25:1
\]
Impactor Operation

Volume control by setting of top curtain

Product control by setting of bottom/third curtain

For P80/P90=20mm
Set 15mm
The crushing chamber in a cone crusher is the most important part.

All other parts in the crusher are "only" there to hold the chamber in place or to create movement of the mantle.
Why so many chambers?

All crushing starts with the chamber!
Why different chambers?

- Maximum energy utilisation.
- Avoid load peaks
- Prevent uneven wear
Each eccentric revolution means a crushing stage
Influence of speed

There are several crushing stages in the chamber

When the falling stone is caught, it is trapped and to some degree pushed upwards.
Influence of speed

Path through crushing chamber

Crushing Zone

Y-coordinate [m]

X-coordinate [m]

269 RPM

360 RPM

579 RPM

9 Strokes

11 Strokes

21 Strokes
Speed v capacity tests.

CAPACITY

![Graph showing speed vs capacity tests with different eccentric speeds and efficiencies.]

CSS=15 mm
CSS=12 mm
CSS= 8 mm

$t_d = 0.01$

$\eta_v = 0.70$
Practice proves theory!

Take Home message
Higher speed:
Lower throughput.
Finer product.
Improved product quality.

Lower speed:
Higher throughput.
Coarser product.
Poorer product quality.
Each stage is represented by a crushing zone

Each ring volume represents the material that is crushed at each eccentric revolution.
The zone with the smallest volume determines the capacity

The capacity is volumetric

Choke zone
Reduced C.S.S.: Increased net capacity

Small volume reduction in feed zone $\Rightarrow$ small total capacity reduction
Much smaller volume in discharge zone $\Rightarrow$ high size reduction ratio

Note: Capacity - C.S.S. relation is approx. linear
Reduced C.S.S.: Consequence map

C.S.S. reduction

- Smaller volume in the crushing chamber
- Risk of packing
- Lower capacity
- Higher pressure
- Higher energy consumption
- Improved shape
- Finer product
- Higher net capacity
- More power
Increased throw resulting in increased chamber volume means:

- higher capacity
- more stones in the chamber to compress
Increased throw: Consequence map

- Consequence: Throw increased
  - Larger average setting
  - Higher flow
  - Higher torque
  - Increased compression
  - More crushing stone-against-stone
  - Packing risk
  - Higher capacity
  - More power needed
  - Higher power consumption
  - Improved shape
  - Higher net capacity
Relation between power and pressure

![Graph showing the relation between power and pressure for different types of crushing: Packing, Fine crushing, and Coarse crushing. The graph indicates the max permitted power for each type of crushing.]
What happens if the feed size changes?

- Smaller feed size
- Capacity up
- Finer product
- Better shape

Bulk density increases - higher risk of packing as feed becomes finer.
What happens if other feed characteristics change?

**Tougher rock**
- Increased crushing force and power draw
- Coarser product size

**Increased moisture content**
- Lower capacity
What happens if other feed characteristics change?

Higher density  ➔  Higher capacity

Improved feed particle shape

More cubical  ➔  Faster flow  ➔  Higher capacity
Rounder shape
Cone Crushers
Product Quality

- Good Flexibility
- Higher crushing forces
- Good shape in the 5-80 mm range
- Uniform reduction ratio
Impactors – HSI and VSI

Product quality

- Better shape
- Good shape in the +40 micron range
- Uneven Reduction
- Limited topsize capacity
- High fines production
Crushing General

Take Home Messages

1. Do you have the optimum chamber fitted to your crusher

2. Where available, do you have the optimum throw
   1&2 are volumetric issues and may well determine the utilisation of the crusher ---remember all crushers work best when continuously choke fed

3. Do you have the crusher setting optimised.

4. Is the feed condition correct—have you removed the risk of packing

5. Do you have the optimum speed
### Operating principles
The crushing result is difficult to predict

<table>
<thead>
<tr>
<th>Crushing result</th>
<th>Input parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chamber size</td>
</tr>
<tr>
<td>Capacity</td>
<td>X</td>
</tr>
<tr>
<td>Power consumption</td>
<td>X</td>
</tr>
<tr>
<td>Crushing force</td>
<td>X</td>
</tr>
<tr>
<td>Product size</td>
<td>X</td>
</tr>
<tr>
<td>Product shape</td>
<td>X</td>
</tr>
<tr>
<td>Product strength</td>
<td>X</td>
</tr>
</tbody>
</table>

*X = Interdependency*
Influencing factors

Take Home Message

All crushers have a volumetric and a mechanical limit.

Toughness of material, feed material grading analysis, volume and reduction ratio all play their part in the ability of the crusher to perform the duty over an acceptable lifecycle.

If any combination of these factors overstress the mechanical capability of the crusher it will be necessary to reduce the influence of another.

EG - The demand for greater throughput at the expense of reduction.
Conclusions

- the work done in a crusher is dependant on

- material factors such as
  1. toughness,
  2. bulk density
  3. feed size analysis

- machinery factors such as
  1. setting
  2. throw
  3. chamber volume
  4. speed

Take Home Message

There are so many variables that to maximise performance it is necessary to understand how these factors and any consequent wear affect the end result.

This can only be done by in-process testing.
Problems

Some areas of concern which destroy good operation with cone crushers
Cone crusher

Pressure Reflects Crushing Force

- Reaction Force $F_1$
- Crushing Force $F$
- Reaction Force $F_2$
- Reaction Force $F_3$
- Area of Piston: $A$

Hydroset pressure

$$p = \frac{F_3}{A} = \frac{F \cdot \cos a}{A}$$

i.e. proportional to $F$
Reaction to uneven, segregated feed

Crushing Force

\[ F_4 + F_5 > F_1 + F_2 \]
\[ F_3 > F_6 \]

As wear becomes uneven the power and pressure fluctuation will become exaggerated, the setting more difficult to control and the product grading and quality will deteriorate.

Zero reaction at any point during the revolution will suggest a portion of the chamber is empty.

Throughout every revolution both power and pressure will fluctuate considerably, causing extreme cyclic stress on machine component parts. This will require the setting to be run wider than necessary.
Misaligned feeding at El Teniente, Chile CH880
Tertiary application

Segregated feed- High pressure amplitudes
Improved segregation

Unsegregated feed- Low pressure amplitudes

Pressure [MPa]

Time x100 [s]
Effects of vertical crushing force

Vertical force taken by single hydraulic cylinder

Vertical force taken by cylinders used to hold topshell to bottomshell
What are the negative effects?

- High power and pressure will cause the crusher to be run at wider than necessary settings resulting in coarser product producing higher recirculating loads with increased conveying, wear and crushing costs.

- Occasionally the necessity for increased crushing will demand increased capital investment.

- Segregated and poorly distributed feeds will cause the crusher liners to wear unevenly, again with deteriorating performance and associated costs.

- This applies also to poorly fed HSI crushers where hammer wear and curtain liner wear is biased to one side.
What are the negative effects?

- Product will become coarser and cubicity, often in critical products, will deteriorate. What cost??

- Segregation and uneven wear will cause reduction in liner life through premature exchange. What cost??

- Segregation and uneven wear will cause reduction in mechanical component life, sometimes leading to traumatic failure and the costs of unplanned stoppages.

- THE CUMMULATIVE EFFECT ----- CONSIDERABLE COST TO THE OPERATION.
Poor feeds-Inclined belt conveyors

A common feed method, but unless considerable care is taken, possibly the most unsatisfactory method of feeding cone crushers.

- Material is segregated by the “tamping” action of the idler sets as material passes over.

- Belt speed.
  1. Material leaving the end pulley follows a parabola. The path depends on the speed of the belt.
  2. Coarse material, with greater mass, will tend to travel further than finer material.
  3. This segregation will become more pronounced the greater the differential size and the higher the conveyor speed.

- Belt width. Improvement in materials and restrictions on capital investment have possibly created a trend towards narrower but higher speed belts. These not only segregate but lack the capability to distribute sufficiently.

- Discharge height.
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