Rock mechanics related to mining: challenges and opportunities

Zong-Xian Zhang

April 26, 2018
Two missions of rock mechanics in mining engineering

• Destroy rock efficiently
• Support rock structures effectively
Relation between rock mechanics and mining engineering

To destroy rock efficiently
To achieve best mining results
To make rock structures safe

Rock drilling
Rock boring & excavation
Open cut
Rock blasting
Secondary fragmentation
Tunneling & drifting
Crushing
Grinding/milling

High recovery
Low dilution
High mining profit

Planning & design
Ore pass
Slope stability
Caving
Seismic events & rock bursts
Roof protection
Rock support
Vibration control
Environment protection
To destroy rock efficiently in:

- Rock drilling
- Rock blasting
- Mechanical boring/excavation
- Tunneling/driftting/shaft sinking
- Crushing & grinding
- Open cut
Rock drilling

Current state in rock drilling
• Rock drilling speed has much potential to increase
• Deviation is still a problem
• Energy efficiency is low (10% in percussive drilling)

Challenges in rock drilling
• Mechanism of breakage in drilling
• Energy consumption and distribution
• Repeat breakage and cutting discharge
• Deep drilling with high confinement and high temperature

Chance to increase drilling speed and energy efficiency

Down-the-hole drill rig from Atlas Copco (Zhang 2016)
Rock blasting

Current state in rock blasting
Experience-dominant desing/plan resulting in low recovery, much damage in surroundings, high vibrations and water contamination

Challenges
• Wastage of explosive energy (up to 50% if no stemming)
• Boulders
• Delay time
• Basic parameters in blasting

Chance to improve rock blasting
• Scientific desig/plan
• Determine delay time by consiering fracture and throw
• Using wave superpositiona and shock collision when needed

Effect of primer position on fragmentation (Zhang 2016)
Mechanical boring/excavation

Current state
• More and more machines are used

Challenges
• Higher excavation speed
• Lower cost

Potential to increase boring speed
• Scientific design for cutters and cutter head
• Discharge of debris/fragments
• Parameters related to rock fracture

Boring speed should be 5-7 times higher than current speed (Zhang 2016)
Tunneling or drifting

Current state

• Drill and Blast method is dominant
• TBM increases

Challenges

• Fractured zone and drill/blast plan in D&B method
• High cost in TBM

Potential to develop in D&B and TBM

• Fractured zone can be reduced in D&B
• Advancing rate in TBM can be increased
• Discharge of debris/fragments can be better

Unsuccessful blasting and drill/blast plan in drifting (Zhang 2016)
Crushing and grinding

Current state
Low energy efficiency in crushing (3-5%) and in grinding (1%) 

Challenges
• To know energy distribution
• To increase energy efficiency 

Potential to develop new techniques/equipment
• To create one m² surface only needs 10 J (N.m) energy for rock.
• In fracture toughness test such energy becomes 190 J.

Fracture toughness increases with loading arte, and flying fragments waste much energy (Zhang 2016)
Open cut in underground mining

Current state
• Mechanical open cut increases
• Drill & blast method is still dominant
• Unsuccessful open cuts are quite many

Challenges
• Cost reduction in mechanical method
• Scientific design in D&B method

Potential to develop
• To reduce cost in mechanical method
• To make correct drill & blast plan in D&B method

Successful and unsuccessful open cuts (Zhang 2016)
To support rock structures effectively in:

- Mining planning
- Layout of underground excavations such as tunnels/drifts and other spaces
- Ore pass design and maintenance
- Slope stability
- Caving (in Sublevel caving and block caving)
- Rock fall and roof protection
- Rock support design
- Vibration control and environment protection
Mining planning

- Sizes of blastholes (large holes cause high vibrations and induce seismic events)
- Drill and blast plans (>10% holes were not detonated)
- Height of main levels (great height reduces cost in development but how to assure successful blasting)
- Downward and upward mining (downward is better in cut-fill method for reducing rock bursts but how to use this in other methods)
Slope stability

Current state
• Slope failure still happens with some casualties
• Blasting, water, etc are main initiation factors

Challenges
• How to reduce the impact from water?
• How to reduce the impact from blasting?

A huge open-pit coal mine has collapsed in eastern India, trapping at least 30 people and killing at least seven, reported by Medhavi Arora and Juliet Perry, CNN, December 30, 2016.
Caving (in Sublevel caving and block caving)

Current state
- Hanging wall caving causes seismic event and dilution in SLC
- Block caving may cause dilution and needs prediction

Challenges
- How to predict the caving in both SLC and BC?
- How to control the caving in BC?

Opportunity
- Monitoring and analysis of seismic events
- Rock fracture theory

Lower picture from Rail Engineer
Rock support design

Current state
• Experience-dominant design, resulting in either too much or too little support
• Cost of rock support increases with increasing mining depth

Challenges
• How to determine correct spacing, length, and other parameters of bolts?
• How to determine the thickness of shotcrete and where we should use meshes?

Opportunity
• To use measurement while drilling (MWD) or other techs to provide sufficient info to support design
• To develop rock support theory
Vibration control and environment protection

Current state
- Blast-caused vibrations are a common problem for mining engineering
- Effective and cheap methods are needed

Challenge
- Limitation of each group of methods

Opportunity
- To apply for detonation theory
- To use rock fracture theory
- To develop attenuation theory of rock
Combining the knowledge in rock destruction and rock support we can:

- Achieve high ore recovery
- Make dilution lower
- Reduce and manage seismic events
- Reduce and manage rock bursts
- Reduce overall mining cost
- Select proper mining method and make other improvements
To achieve high ore recovery in mining

Annual mineral losses in mining over the world (estimated on the basis of 10% ore loss)

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Production in 2014 (Mt)</th>
<th>Ore loss estimated in 2014 (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumina</td>
<td>107</td>
<td>11.9</td>
</tr>
<tr>
<td>Coal</td>
<td>8085</td>
<td>898.3</td>
</tr>
<tr>
<td>Copper</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>Iron</td>
<td>3378</td>
<td>375.3</td>
</tr>
<tr>
<td>Lead</td>
<td>5.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Nickel</td>
<td>2.1</td>
<td>0.23</td>
</tr>
<tr>
<td>Zinc</td>
<td>13.7</td>
<td>1.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Production in 2014 (t)</th>
<th>Ore loss estimated in 2014 (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>3020</td>
<td>336</td>
</tr>
<tr>
<td>Silver</td>
<td>27427</td>
<td>3047</td>
</tr>
<tr>
<td>Tin</td>
<td>355000</td>
<td>37222</td>
</tr>
<tr>
<td>Tungsten</td>
<td>85300</td>
<td>9478</td>
</tr>
<tr>
<td>Uranium</td>
<td>66000</td>
<td>7333</td>
</tr>
</tbody>
</table>
To achieve high ore recovery in mining

Current state of ore loss in mining engineering
• The mines with ore loss less than 10% are few, and many mines with ore loss up to 20%, e.g. some sublevel acving mines.
• Ore loss depends on mining method, rock blasting, rock drilling, production management, rock mechanics, rock support, etc.

Challenge
• How to realize optimum fragmentation so as to increase recovery?
• How to reduce ore loss due to seismic events and rock bursts?
• How to make sufficient rock support to assure high recovery?

Opportunity
• Optimization of whole size-reduction chain
• Necessary, sufficient and economic rock support
To reduce dilution in mining

Current state of ore loss in mining engineering
• Similar to ore loss, dilution in mining operation is also high. High dilution increases mining cost and causes environmental problem.
• For some mining methods such as sublevel caving, dilution may be higher than ore loss. For example, one mining company has an ore loss of 5.9 Mt per year. At the same time, its dilution is 6.8 Mt.

Challenges
• How to control caving in block caving mining?
• How to predict caving/subsidence area?
• How to improve fragmentation in mining?
• How to determine correct cut-off grade?

Opportunity
• Caving theory needed
• Relation between cut-off grade and blasting as well as management
To reduce and manage seismic events

Current state
- Both quantity and scale of seismic events increase with increasing mining depth
- Seismic events often increase mining costs and ore loss

Challenges
- What are the mechanisms of seismic events?
- How to predict seismic events?
- How to manage seismic events in mining production?
- How to release energy and stress concentration?

Opportunity
- It is difficult to predict seismic events but it should be possible to a certain extent since seismic events are induced by mining.
- It is possible to manage seismic events by combining mining activity/planning and seismic events.
To reduce rock bursts

Current state
• Rock bursts increase with increasing mining depth
• Rock bursts often increase mining costs

Challenges
• Difficult to know the mechanisms of rock bursts
• Difficult to predict seismic events
• Difficult to release energy and stress concentrated

Opportunity
• Lab tests needed
• Investigation on the mechanism
• Numerical simulation
Reduce overall mining cost

Current state of cost distribution in hard rock mining industry (Bowen 2015)

- Load & Haul: 23%
- Mill: 67%
- Grade Control: 5%
- Drill & Blast: 5%
Example for increasing ore recovery at Malmberget mine, LKAB (40 test rings and 210 ordinary rings)
Example for increasing ore recovery at Malmberget mine, LKAB (148 test rings and 110 ordinary rings)
Example for improving fragmentation at Malmberget mine, LKAB (left: lowerest primer; right: middle primer)
Example for reducing ore loss and improving safety at Malmberget mine, LKAB
(380 000 tons ore loss due to hanging roofs in two years)

The hanging roof can be broken down by using an easy method based on shock waves and rock fracture theory.