Analysis of stresses produced and dust generation during rock cutting by ANSYS software

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ABSTRACT

Underground coal mining operations continue to increase production as mining equipment and practices are improved. Unfortunately, increased production also results in the potential for increased Respirable dust generation and worker exposure. In response, operations are applying basic controls at elevated levels and looking to emerging technologies in an effort to better control Respirable dust levels. Ventilating air and water sprays remain the basis of dust control strategies for both longwall and continuous mining operations, and the level of application for these controls continued to increase. In addition, new technologies are emerging that have the potential to further reduce dust levels. In this Paper an attempt is made to study the Stresses Produced and its Influence on Dust generation at different Attack angle and force applied on the cutting material.

Keywords: Rock cutting, Mechanical properties, Cutting parameters, Airborne respirable dust, Stresses.

1. Introduction

The high demand for coal production has increased the need for mechanical coal cutting in underground coal mines. On the other hand our coal reserves are shrinking, forcing operators to mine thin coal seams and subsequently to cut roof/floor rocks in order to maintain sufficient clearance for equipment. Enormous miles of entries are developed by these continuous miners for long wall operations as well as bord and pillar mining (Khair, 2001). The amount of repairable dust generated by excavating coal and cutting roofs with continuous mining machines is the major concern to the mining industry. Dust is an inevitable product of mining, given by the nature of mining operations such as cutting/drilling, loading and transportation of coal. It is dispersed into the mine atmosphere by the ventilating air current, and travels downwind. Once airborne, the Respirable dust particles are difficult to capture and remove as they fall very slowly because of associated aerodynamic properties. As a result, miners are exposed to high Respirable dust concentration levels. Respirable dust is a continuing problem in the mine environment, where it adversely affects the safety and productivity of a miner. In underground coal mining, dust particles ranging from 1 to 10 micron sizes (Respirable particulate matter ranges from 1-5µm and greater than 5µm are suspended particulate matter as per ISO 7708, 1995), In addition, dust also results in obscuring visibility and affects general mobility of the miners, and may also lead to sudden catastrophic incidences of explosion.

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During last three decades with the introduction of the mechanization, i.e. Road header, Continuous Miner and Double Ended Ranging Drum Shearer in the underground coal mining, it has become a greater menace than ever posing threat to the health and safety of miners. The majority of Respirable dust generated by mechanical miners is the result of material that is crushed directly under the individual bits/cutters on the cutter head. Figure 1 shows the crushed zone underneath a bit and the resulting fractures in the rock that lead to production of Respirable dust. Reducing the amount of dust produced will reduce the risk of dust getting airborne in the working area (Asbury et al., 2002).

![Crushed zone where dust is generated.](image)

**Figure 1:** Crushed zone where dust is generated (Asbury et al., 2002)

The main machine parameters that influence the cutting efficiency of a continuous mining machine include bit spacing, depth of cut and bit geometry. Through a correct combination of bit spacing and depth of cut, two adjacent grooves start interacting and the land/ridge between the two cuts can be removed which will result in large chip formation and less dust generation.

1. **Objectives**

   The main objectives of this research study are:

   1. Fabrication of experimental set up of rock cutting machine with necessary arrangement like holding the rock specimen, for changing Cutting drum, RPM and thrust applied
   2. To study the effect of Physico-Mechanical properties and mineralogical composition of samples on cutting rate and dust generation
   3. To study the effect of operational parameters of RPM and thrust and torque on cutting rate and dust generation

1.2 **Literature survey**

   The mining industry has centered its attention on mastering the goal in decreasing the amount of respirable dust generated during the cutting process. A better understanding of the influence of several parameters, including both machine-controlled and operator-controlled, during the rock cutting process is required. Important parameters affecting coal cuttability rate are physical and mechanical properties of coal/rock such as: density, uniaxial compressive strength, tensile strength and shear strength etc. Chemical composition of coals may directly or indirectly affect the coal cuttability. Increasing of 27% and 22% in moisture and volatile material respectively in coals may cause decrease in strength of coal, but less than these values,
coal strength may increase (Shahriar et al., 2009). Some of the minerals like Quartz can play a major role on erosion of cutter of coal winning machines, affecting the cutter life considerably. In the past, much research has been carried out to select the design parameters for cutting tools on a trial and error basis. The mining industry is yet to receive a solution, which could provide optimum parameters like type of bit, bit angle and angle of attack etc, for coal/rock cutting in underground coal mines. (Rizwan.A.Qayyum, 2003)

While mechanical coal cutting is a relatively well-understood topic, the technique has changed little in recent years. Primary enhancements have tended to centre on metallurgical improvements and advancements in the manner in which the tools engage the face. This, as a general observation, indicates that the understanding of the involved mechanics and technology is optimal, although a cautionary note must be sounded from the preceding section, which examined the generic or petrographic content related mechanical properties of South African coal. In general, it can be concluded that several authors (Macgregor, 1983, McVey, 1986, and Falcon, 1987) have alluded to differences between South African coals and those of Europe or America, that inherently make South African coal more difficult to cut.

Mechanized coal cutting traditionally makes use of tools that are dragged across the face, typically driven by a rotary drum, in order to liberate the coal. These tools are commonly described as either point attack or radial drag bits, so named as these terms best describe their generic method of engaging the coal. The mechanisms of cutting using drag bits are well understood, and whilst there have been advances in cutting methods in recent years, the generic tool shapes have changed little.

2. Cutting parameters

The influence of common parameters on drag tool cutting, such as geometry and speed, is depicted in Figure 2 and Figure 3 which graphically summarizes the different cutting parameter.

The following parameters commonly influence the cutting tool operations

2.1 Rake angle

The angle of the cutting face relative to the work. There are two rake angles, namely the back rake angle and side rake angle, both of which help to guide chip flow.

2.1.1 Back clearance angle

The angle between a plane containing the end surface of a cutting tool and a plane passing through the cutting edge in the direction of cutting motion. The back clearance angle should not be less than 5° and not greater than 10°.

2.1.2 Attack angle

The attack angle is the angle between the axis of the tool and the surface being cut. The attack angle is usually between 45° and 55° for rocks of lower strength. The most common tip angle is 75°. The preferred rake and back clearance angles should not be less than 25° and not more than 10° for conical bits.
2.1.3 Cutting speed

Cutting speed has no significant influence on the magnitude of the pick forces provided the wear effect has been discounted.

2.1.4 Line spacing

Line spacing is the distance between adjacent tools or picks in the axial direction, on the cutter or shearer drum. If the line spacing is too close, the cutting is inefficient due to over-crushing of the rock, and if it is too wide, the tool cuts in an unrelieved mode (tensile fractures from adjacent cut cannot reach each other to form a chip), creating a groove-deepening situation, resulting in the formation of a rib between cuts. The minimum specific energy is obtained with an optimum spacing to depth ratio has indicated to be in the region of 2:1.

![Line spacing diagram](image)

**Figure 2:** Line spacing is the distance between adjacent tools or picks (Ismail et al., 2002)

2.1.5 Depth of cut

It is the thickness of material removed by one pass of the cutting tool. It can be seen that the specific energy improves substantially as the depth of cut is increased. This result has been proved both in the laboratory and by in-situ testing of an instrumented continuous miner.

![Depth of cut diagram](image)

**Figure 3:** Interaction of bit with rock and bit geometry (Ismail et al., 2002)
3. Mechanical properties

3.1 Uniaxial compressive strength

Compressive strength is the capacity of a material to withstand axially directed compressive forces. The most common measure of compressive strength is the uniaxial compressive strength or unconfined compressive strength. Usually compressive strength of rock is defined by the ultimate stress. It is one of the most important mechanical properties of rock material, used in design, analysis and modeling.

3.2 Young's modulus

Young's Modulus is modulus of elasticity measuring of the stiffness of a rock material. It is defined as the ratio, for small strains, of the rate of change of stress with strain. This can be experimentally determined from the slope of a stress-strain curve obtained during compression or tensile tests conducted on a rock sample.

3.3 Poisson's ratio

Poisson’s ratio measures the ratio of lateral strain to axial strain, at linearly-elastic region. For most rocks, the Poisson’s ratio is between 0.15 and 0.4. As seen from early section, at later stage of loading beyond linearly elastic region, lateral strain increase fast than the axial strain and hence lead to a higher ratio.

Table 1: Mechanical properties of Rocks

<table>
<thead>
<tr>
<th>Rock</th>
<th>Sample Collected</th>
<th>Density (Kg/cm$^2$)</th>
<th>Compressive strength (MPa)</th>
<th>Young’s Modulus (MPa)</th>
<th>Poisson’s Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>5 Incline Mines, SCCL, AP</td>
<td>2.2</td>
<td>14.2</td>
<td>18.2</td>
<td>0.24</td>
</tr>
<tr>
<td>Dolomite</td>
<td>Chaitanya Industries, Mudhapur, Bagalkot</td>
<td>2.5</td>
<td>25.4</td>
<td>29</td>
<td>0.16</td>
</tr>
<tr>
<td>Limestone</td>
<td>JK cements, Mudhapur, Bagalkot</td>
<td>2.3</td>
<td>70.3</td>
<td>15.1</td>
<td>0.31</td>
</tr>
</tbody>
</table>

3.4 Description of rock cutting machine

Rock cutting machine is a prototype model of a Road header, Continuous Miner or Coal Shearer used for cutting coal/ rock in underground mines/tunneling which is installed at NITK, Suatkal as shown in Figure 4.

Rock cutting machine consists of a firm base with two parts protruding: one of the part has a prime mover (motor) mounted on it. A base plate attached to the motor has guide ways, which helps in moving to and fro movement and sideways also. A Motor is in turn is attached to a shaft pulley by belt drive. The cutter head will be attached to the shaft by a flange. Cutter head consists of a drum head with number of bits mounted on it.
The other part of rock cutting machine has firm sample holder, in turn connected to a hydraulic cylinder, which can provide sideways movement during cutting operation and a dust collecting bin.

### 3.5 Sieve analysis

A sieve analysis (or gradation test) is a practice or procedure used (commonly used in civil engineering) to assess the particle size distribution of a granular material. The size distribution is often of critical importance to the way the material performs in use. A sieve analysis can be performed on any type of non-organic or organic granular materials including sands, crushed rock, clays, granite, feldspars, coal, and soil, a wide range of manufactured powders, grain and seeds, down to a minimum size depending on the exact method. Being such a simple technique of particle sizing, it is probably the most common.

#### Procedure

1. Arrange the nest of Sieves starting from 0.3, 0.212, 0.18, 0.15, 0.106 mm (0.3 mm sieve at the top and 0.106 mm sieve at bottom),
2. Place the sample material at the top most sieves that is on 0.3 mm sieve.
3. Place the sieve set on the sieve shaker and allows the machine to run for 5 min.
4. Weigh the material which is retained in each sieve and the bottom most pan to the most nearest of 0.1 gm. Tabulate the results in the standard form of sieve analysis.

#### Table 2: Sieve analysis data for 45°

<table>
<thead>
<tr>
<th>Sample</th>
<th>Coarse (gms)</th>
<th>Medium (gms)</th>
<th>Fine (gms)</th>
<th>TOTAL (gms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>239.4</td>
<td>2.4</td>
<td>1.7</td>
<td>243.5</td>
</tr>
<tr>
<td>Dolomite</td>
<td>21.3</td>
<td>4.5</td>
<td>4.2</td>
<td>30</td>
</tr>
<tr>
<td>Limestone</td>
<td>29.7</td>
<td>10.9</td>
<td>17</td>
<td>57.6</td>
</tr>
</tbody>
</table>

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Table 3: Sieve analysis data for 55°

<table>
<thead>
<tr>
<th>Sample</th>
<th>Coarse (gms)</th>
<th>Medium (gms)</th>
<th>Fine (gms)</th>
<th>TOTAL (gms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>187.8</td>
<td>1.9</td>
<td>1.4</td>
<td>191.1</td>
</tr>
<tr>
<td>Dolomite</td>
<td>19.3</td>
<td>3.2</td>
<td>3.7</td>
<td>26.2</td>
</tr>
<tr>
<td>Sandstone</td>
<td>27.1</td>
<td>9.5</td>
<td>16.5</td>
<td>53.1</td>
</tr>
</tbody>
</table>

4. Displacement of rock

Figure 5: Displacement Occurred during Cutting of Coal with Cutting angle at 45°

Figure 6: Displacement Occurred during Cutting of Coal with Cutting angle at 55°

Figure 7: Displacement Occurred during Cutting of Dolomite with Cutting angle at 45°

Figure 8: Displacement Occurred during Cutting of Dolomite with Cutting angle at 55°
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Figure 9: Displacement Occurred during Cutting of LimeStone with Cutting angle at 45°

Figure 10: Displacement Occurred during Cutting of Lime Stonewith Cutting angle at 55°

4.1 Von Mises stress of rock

Figure 11: Von Mises Stress occurred during cutting coal with Cutting angle at 45°

Figure 12: Von Mises Stress occurred during cutting coal with Cutting angle at 55°

Figure 13: Von Mises Stress occurred during cutting Dolomite with cutting angle at 45°
5. Result

5.1 Displacement occurred during cutting of rocks

Table 4: Displacement occurred in Rocks at an angle of 45°

<table>
<thead>
<tr>
<th>Rock Name</th>
<th>Attack Angle</th>
<th>For First Cut</th>
<th>For Second Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DMX</td>
<td>SMN</td>
</tr>
<tr>
<td>Coal</td>
<td>45°</td>
<td>0.904E-03</td>
<td>-0.834E-03</td>
</tr>
<tr>
<td>Dolomite</td>
<td></td>
<td>0.100E-03</td>
<td>-0.938E-04</td>
</tr>
</tbody>
</table>
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Table 5: Displacement occurred in rocks at an angle of 55°

<table>
<thead>
<tr>
<th>Rock Name</th>
<th>Attack Angle</th>
<th>For First Cut</th>
<th>For Second Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DMX</td>
<td>SMN</td>
<td>SMX</td>
</tr>
<tr>
<td>Coal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.00128</td>
<td>-0.00118</td>
<td>0.428E-05</td>
</tr>
<tr>
<td>Dolomite</td>
<td>55°</td>
<td>0.182E-03</td>
<td>-0.168E-03</td>
</tr>
<tr>
<td>Limestone</td>
<td></td>
<td>0.108E-03</td>
<td>-0.934E-04</td>
</tr>
</tbody>
</table>

5.2 Von Mises stresses occurred during cutting of rocks

Table 6: Von Mises Stresses occurred in rocks at an angle of 45°

<table>
<thead>
<tr>
<th>Rock Name</th>
<th>Attack Angle</th>
<th>For First Cut</th>
<th>For Second Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DMX</td>
<td>SMN</td>
<td>SMX</td>
</tr>
<tr>
<td>Coal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.904E-03</td>
<td>0.206E-04</td>
<td>0.044964</td>
</tr>
<tr>
<td>Dolomite</td>
<td>45°</td>
<td>0.100E-03</td>
<td>0.288E-04</td>
</tr>
<tr>
<td>Limestone</td>
<td></td>
<td>0.945E-04</td>
<td>0.172E-04</td>
</tr>
</tbody>
</table>

Table 7: Von Mises stresses occurred in rocks at an angle of 55°

<table>
<thead>
<tr>
<th>Rock Name</th>
<th>Attack Angle</th>
<th>For First Cut</th>
<th>For Second Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DMX</td>
<td>SMN</td>
<td>SMX</td>
</tr>
<tr>
<td>Coal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.00128</td>
<td>0.292E-04</td>
<td>0.63628</td>
</tr>
<tr>
<td>Dolomite</td>
<td>55°</td>
<td>0.128E-03</td>
<td>0.493E-04</td>
</tr>
<tr>
<td>Limestone</td>
<td></td>
<td>0.102E-03</td>
<td>0.249E-04</td>
</tr>
</tbody>
</table>
When the rock was cut with a cutting angle of 45°, the stresses induced is less and the dust generated is more. But, when the rock was cut with a cutting angle of 55°, the stresses induced is more and the dust generated is less. Hence, we got good results. At an angle of 55°, it is very effective and best suited for Rock Cutting.

5.3 Conclusion

1. The Experiment was conducted on 45° and 55° Attack angles and the results were found good in 55°. Both the strength implied is more and dust generated is less.

2. By using this method, we are able to reduce the dust generation in coal mine, experiment was conducted on lime stone and dolomite also, the results are positive and the dust generation is less.

3. Due to the less dust generated, workers efficiency will increase and can reduce the occupational health diseases.

6. References


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