Rockburst Prediction of Deep Mining in Tectonic Stress Mine

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Abstract: As more than 40 years’ mining in Chengchao Iron Mine, the excavation depth now is arriving at -600m level, and rockburst is becoming one of the main safety problems during the deep mining in the tectonic stress mine, so as to predict the possibility and intensity, rock specimens from the depth of -430 meters to -700 meters are obtained for systematical rocks mechanics testing. Based on various prediction criteria, the different intensity of the wall rock for rockburst are ascertained. Combined with the measured in-situ stresses, the model of the in-situ stresses field is established, and elastic strain energy of wall rock is confirmed by the strain numerical simulation, judging by the engineering research and site monitoring, the critical mining depth for rockburst is obtained. At last, according to the above analysis, the possibility of rockburst during deep mining and its potential depth in Chengchao Iron mine is predicted.

Keywords: tectonic stress mine; deep mining; rockburst; prediction

1. Introduction

Chenchao Iron Mine is one of the primary mines of Wuhan Iron and Steel Group, nowadays, the driving project has reached the deep-seated ore body which the depth is 1100m, and the depth of central mining has reached deeper than -420m. As the depth of mining fields increasing, the integrality of rock mass has become better, the in-situ stresses of the operation fields has become greater, the rigidity and brittleness of rock mass has also become higher, which has formed the condition for rockburst. Therefore, the prediction research is very urgent and indispensable to ensure the safety for the people and the equipments.

Rockburst is the common disaster in the high in-situ stress underground projects, and its regular representation is rock looseness, desquamation, ejection and even rock flacks[1]. At present, the scholars have made great progress in rockburst prediction researches, and the methods are primarily conclude into two types, academic analytical method and actual measurement method. These two methods both have their merits and demerits[2]. Academic analytical method is more applicable in the initial stage of projects when the rock specimens can be analyzed in the lab, but this method is based on different mechanism which is not mature so far, and the occurrence of rockburst is the result of many factors, so there would be error if few factors are taken into consideration, and the prediction precision is not so satisfied. As for the actual measurement method, its precision is much higher, but it also has its disadvantages, such as the imperfection of the metrical methods and equipments. Whereas the deep mining in Chenchao Iron Mine is at the planning stage, the actual measurement is not so available, so analytical method is primarily adopted in this paper. Based on various prediction criteria, rocks for different possible intensities were ascertained. Combined with field measured ground stress, the model of the in-situ stress field is established, and by the numerical simulations of the strain during deep mining, elastic strain energy of surrounding rocks is confirmed. According to the analysis, the possibility of rockburst during deep mining in Chengchao Iron mine is predicted, and the critical depth of rockburst is deduced.

2. Prediction Based on Mechanical Properties Testing

2.1 Rock Properties Testing

Combined with the locale situation, the specimens of marbles, magnetite and granite are obtained at the V ore body on line W41(depth at -520m to -650m), fig.1 is the geological section plane on line W41 in Chengchao Iron Mine. The drilling direction is vertically downwards from the middle part of the ore body to the substrate. The specimens are processed to make sure that length is twice larger than diameter, the convexity precision of the two sections is not more than 0.05mm, and the acceptable deviation of two vertical sections is 0.25°.

2.1.1 Compressive Strength Test

The diameter of specimens is 48mm, processed by the rigid presser at the static load. The equation for compressive strength is:

\[ \sigma_c = \frac{P}{S} \]  

Where \( \sigma_c \) is the compressive strength; \( P \) is the broken load; \( S \) is the load area. The average compressive strengths are listed in Table 1.
2.1.2 Tensile Strength Test
The Brazilian test is adopted for the tensile strength test, the equation is:
\[ \sigma_t = \frac{2P}{\pi dl} \]  
(2)
Where \( \sigma_t \) is the tensile strength; \( d \) is the diameter of rock, \( l \) is the length. The average tensile strengths are shown in Table 1.

2.1.3 Crack Test
The crack test is processed on normal presser. Specimens are loaded at definite speed until they are broken, so the crack kinetic energy is the product of weight and flying distance of the fragments. Tab.2 is the results of the crack kinetic energy.

![Note: Fe-iron ore, M-marble, γ-granite. Fig.1 Geological section plane on line W41 in Chengchao Iron Mine](image)

<table>
<thead>
<tr>
<th>Number</th>
<th>Depth(m)</th>
<th>Rock name</th>
<th>Direction</th>
<th>Direction</th>
<th>( \sigma_c ) (MPa)</th>
<th>( \sigma_t ) (MPa)</th>
<th>E(GPa)</th>
<th>( \mu )</th>
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<td>116.2</td>
<td>6.0</td>
<td>56.1</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Note "//" is the parallel direction of bedding; "\( \perp \)" is the vertical direction of bedding.

<table>
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<tr>
<th>Number</th>
<th>Lithology</th>
<th>Dimension</th>
<th>Total weight(g)</th>
<th>Flying distances(cm)</th>
<th>Crack kinetic energy (cm.g)</th>
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</thead>
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<td></td>
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<td>Length (mm)</td>
<td>Weight of fragments(g)</td>
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<td>25</td>
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<tr>
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<td>10.5</td>
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</tr>
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<td>MS06V</td>
<td>Granite</td>
<td>48.3</td>
<td>10.3</td>
<td>499</td>
<td>15</td>
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</tbody>
</table>

2.1.4 Complete Stress-Strain Curve Test
Rock complete stress-strain curve is obtained on the MTS-815.3 servo testing machine under the static loading. The loading rate is controlled according to transverse strain by \((1-5) \times 10^{-6}\).

2.1.5 Loading and Unloading Test
Rock specimens loading and unloading test is also processed on the MTS-815.3 servo testing machine under the static loading, as the load is unloaded to zero at one time. The loading rate is controlled according to transverse strain by \((1-5) \times 10^{-6}\).
2.2. Propensity Analyses for Rockburst

2.2.1 Intensity Brittleness Index and Evaluation

According to compressive strength and tensile strength of rock specimens, the rock intensity brittleness index is defined by this equation:

\[ B = \sigma_c / \sigma_t \]  

(3)

Where \( B \) is the intensity brittleness index; \( \sigma_c \) is compressive strength (MPa); \( \sigma_t \) is tensile strength (MPa).

The results are listed in Table 3, and intensity classification is as follow\(^{[3]}\):

\[
\begin{align*}
B \leq 10 & \quad \text{none} \\
10 < B \leq 14 & \quad \text{weak rockburst} \\
14 < B \leq 18 & \quad \text{medium rockburst} \\
18 < B & \quad \text{strong rockburst}
\end{align*}
\]

(4)

2.2.2 Deformation Brittleness Index and Evaluation

According to total deformation and permanent deformation of rock specimens before loading to compressive strength, the deformation brittleness index \( K_u \) is defined by the equation:

\[ K_u = U / U_i \]

(5)

Where \( U \) is the total deformation; \( U_i \) is permanent or plastic deformation. The intensity classification is\(^{[4]}\):

\[
\begin{align*}
K_u \leq 2.0 & \quad \text{none} \\
2.0 < K_u \leq 6.0 & \quad \text{weak rockburst} \\
6.0 < K_u \leq 9.0 & \quad \text{medium rockburst} \\
9.0 < K_u & \quad \text{strong rockburst}
\end{align*}
\]

(6)

Because it is not easy to control the load to get the compressive strength, 90% of the maximal load is adopted, and then unload to zero. The calculated results are listed in Table 3.

2.2.3 Elastic Energy Index and Evaluation

Kidybinski from Poland first quoted the concept of elastic energy index which was defined by Stecowka and Domzal to determine the possibility of rockburst\(^{[5]}\), this index is the ratio of elastic deposited energy to plastic deformation energy, the equation is:

\[ W_{et} = \Phi_sp / \Phi_s \]

(7)

Where \( W_{et} \) is the elastic energy index; \( \Phi_sp \) is the elastic deposited energy (KJ); \( \Phi_s \) is the plastic deformation energy (KJ). As shown in Fig.2, the areas encircled by the loading and unloading curve denote the value of energy. In theory, \( W_{et} \) is got when we load to the maximal strength, but it’s not easy to control, so we load to 80%~90% of the maximal strength, and then unload to zero.

Elastic energy index is also called impact probability index, its value reflects the magnitude of impactive energy, the results are listed in Table 3, and its in intensity classification equation is:

\[ W_{et} < 2.0 \quad \text{none} \]
\[ 2.0 \leq W_{et} < 5.0 \quad \text{medium rockburst} \]
\[ W_{et} \geq 5.0 \quad \text{strong rockburst} \]

(8)

The energy ratio index (\( \eta \)) is defined in 1973 by Mottycka: \( \eta \) is the ratio of impact elastic energy(\( \Phi_o \)), the equation is given by:

\[ \eta = \left( \Phi_o / \Phi_s \right) \times 100\% \]

(9)

Where \( n \) is the number of the fragment, \( m_i \) is the weight of each fragment; \( v_i \) is the flying speed of each fragment; \( \sigma_{max} \) is the maximal stress; \( \epsilon_{max} \) is the maximal elastic strain.

The critical classification equation is:

\[ \eta \leq 3.5\% \quad \text{none} \]
\[ 3.5\% < \eta \leq 4.2\% \quad \text{weak rockburst} \]
\[ 4.2\% < \eta \leq 4.7\% \quad \text{medium rockburst} \]
\[ \eta > 4.7\% \quad \text{strong rockburst} \]

(10)

The indexes are calculated and the evaluation is shown in Table 3.

According to the data in Table 3, magnetite and granite wall rock have the probability of medium to strong rockburst, for the marble rock mass, though it’s deduced that there is no rockburst probability based on intensity brittleness index, deformation brittleness index and elastic energy index, but it’s concluded that there is rockburst probability according to energy ratio index, so it is not very exact to just take the lab test indexes into consideration, and it’s essential to make a reconnaissance and survey of the engineering geology and in-situ stress. The strain of the rock mass is calculated in the next section with the three-dimensional finite element program.
Table 3 The general prediction indexes of the rock specimens

<table>
<thead>
<tr>
<th>Number</th>
<th>Depth(m)</th>
<th>B</th>
<th>Ku</th>
<th>WET</th>
<th>η(%)</th>
<th>Evaluation</th>
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</thead>
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<tr>
<td>MS01H</td>
<td>520</td>
<td>7.75</td>
<td>2.5</td>
<td>1.53</td>
<td>3.91</td>
<td>none</td>
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<td>1.42</td>
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<td>medium</td>
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<td>540</td>
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<td>6.5</td>
<td>3.94</td>
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<td>medium</td>
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<td>540</td>
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<td>3.78</td>
<td>8.56</td>
<td>medium</td>
</tr>
<tr>
<td>MS03H</td>
<td>590</td>
<td>15.9</td>
<td>11.02</td>
<td>7.82</td>
<td>4.23</td>
<td>medium</td>
</tr>
<tr>
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<td>590</td>
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<td>7.56</td>
<td>5.62</td>
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</tr>
<tr>
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<td>1.85</td>
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<td>none</td>
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<td>1.82</td>
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<td>5.23</td>
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<td>10.51</td>
<td>strong</td>
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</tbody>
</table>

3. Prediction based on the In-Situ Stress and Numerical Calculation

Chenchao Iron Mine belongs to the tectonic stress mine, the existence of high in-situ stress has accelerated the accumulation of huge elastic strain energy, which is the essential condition for rockburst. So it is very necessary to calculate the strain of wall rocks. Therefore, the reconnaissance and survey of the engineering geology and in-situ stresses is made to establish the in-situ field model as follow:

\[
\sigma_{h\text{max}} = 0.82 + 0.0429H \\
\sigma_{h\text{min}} = 0.69 + 0.0285H \\
\sigma_c = 0.53 + 0.0311H
\]

Where \( \sigma_{h\text{max}} \) is the maximal horizontal principal stress, \( \sigma_{h\text{min}} \) is the minimal horizontal principal stress, \( \sigma_c \) is the vertical principal stress, \( H \) is the depth of measuring point.

As the measured results shows, there are high in-situ stresses in Chenchao Iron mine. For the depth of -600m level, the maximal principal stress can be 26 Mpa to 35 Mpa.

3.1 Prediction based on the Shear Stress Index

The shear stress index both considers the load condition of rock mass and the mechanical characteristic of rocks. It is the ratio of shear stress (\( \sigma_\theta \)) to the compressive strength (\( \sigma_c \)), researches have been shown that:

\[
\begin{align*}
T &
\begin{cases}
\leq 0.3 & \text{none} \\
0.3 < T \leq 0.5 & \text{weak rockburst} \\
0.5 < T \leq 0.7 & \text{medium rockburst} \\
T > 0.7 & \text{strong rockburst}
\end{cases}
\end{align*}
\]

According to the result of ANSYS, the results are calculated as shown in Table 4.

Table 4 The evaluation based on T index

<table>
<thead>
<tr>
<th>Depth(m)</th>
<th>Rock Name</th>
<th>( \sigma_\theta ) (MPa)</th>
<th>( \sigma_c ) (MPa)</th>
<th>T</th>
<th>Evaluation</th>
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</thead>
<tbody>
<tr>
<td>499</td>
<td>Marble</td>
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<td>610</td>
<td>Granite</td>
<td>89.9</td>
<td>126.3</td>
<td>0.712</td>
<td>Medium-Strong</td>
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</table>

Where \( \sigma_1, \sigma_2, \sigma_3 \) respectively is the principal stress and \( \varepsilon_1, \varepsilon_2, \varepsilon_3 \) respectively is the principal strain of the rock.

The calculated results show that there is high elastic strain energy in the wall rock mass, for example:

- In the wall rock mass of the -499m level, the maximal elastic strain energy is 78.2kJ/m³;
- In the wall rock mass of the -520m level, the maximal elastic strain energy is 119.5kJ/m³;
- In the wall rock mass of the -540m level, the maximal elastic strain energy is 126.2kJ/m³;
- In the wall rock mass of the -580m level, the maximal elastic strain energy is 117.8kJ/m³;
- In the wall rock mass of the -590m level, the maximal elastic strain energy is 125.9kJ/m³;
- In the wall rock mass of the -610m level, the maximal elastic strain energy is 138.5kJ/m³;

3.2 Prediction based on the Elastic Strain Energy Index

According to the survey of the engineering geology and the measured in-situ stresses, the stress and strain of wall rocks is calculated with a numerical simulation program, so the elastic strain energy can be got by the stress and strain with the equation as follow[6]:

\[
W_e = 0.5(\sigma_1\varepsilon_1 + \sigma_2\varepsilon_2 + \sigma_3\varepsilon_3)
\]
As the theoretical study and field monitoring indicated, when the elastic strain energy is larger than 89 kJ/m², there could be rockburst probability for the tectonic stress mine. So we can get the conclusion from the data above that there could be rockburst in the wall rock when the mining depth is deeper than the -520m level, as we can conclude that the critical depth for the tectonic stress mine is -520m level.

4. Conclusions

The conclusion that the wall rocks of V ore body on line W41 have high elastic strain energy can be affirmed through the compressive strength test, tensile strength test, loading unloading test, crack test and the numerical simulation, and Chengchao iron mine has the probability of rockburst during deep mining. Though it is mentioned that the marble rock mass don’t have the probability of rockburst according to mechanical testing, but as a metallic mine, there is high in-situ stress during deep mining, we deduce the probability of medium rockburst in the marble rock mass at the -520m level by the numerical calculation because of the high shear stress. So we get the conclusions here: during the deep mining in Chengchao Iron Mine, the critical depth of rockburst is at the -520m level, and rockburst for the probability of medium intensity is at the -550m level. When it comes to the deeper level, as the quality of rock mass become well, and the shear stress is very high, the probability of strong rockburst in the granite wall rock at the -600m level will become very high.

References