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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 Cheng-chao 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 0.25º.

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:

$$\sigma_c = P / S \qquad (1)$$

Where σ_c is the compressive strength; P is the broken load; S is the load area. The average compressive strengths are listed in Table 1.

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2.1.2 Tensile Strength Test

The Brazilian test is adopted for the tensile strength test, the equation is:

$$\sigma_t = 2P/\pi dl \qquad (2)$$

Where σ_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.
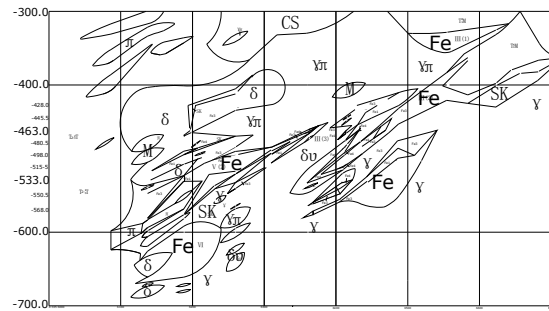
Note: Fe-iron ore, M-marble, γ-granite.
Fig.1 Geological section plane on line W41 in Chengchao Iron Mine

Table 1 Mechanical parameters of the rocks

Number	Depth(m)	Rock name	Direction	σ_c (MPa)	σ_t (MPa)	E(GPa)	μ
MS01H	520	Marble	//	55.8	7.2	31.2	0.26
MS01V	520	Marble	⊥	58.5	7.8	35.1	0.27
MS02H	540	magnetite	//	116.4	8.1	36.2	0.31
MS02V	540	magnetite	⊥	103.8	7.7	35.0	0.35
MS03H	590	Granite	//	120.6	7.6	56.2	0.21
MS03V	590	Granite	⊥	111.6	6.8	52.3	0.23
MS04H	499	Marble	//	51.5	6.8	38.2	0.28
MS04V	499	Marble	⊥	56.8	7.2	36.5	0.32
MS05H	580	Magnetite	//	110.3	7.6	39.5	0.29
MS05V	580	Magnetite	⊥	108.3	7.9	36.1	0.31
MS06H	610	Granite	//	126.3	6.2	59.9	0.21
MS06V	610	Granite	⊥	116.2	6.0	56.1	0.24

Note " // "is the parallel direction of bedding; " ⊥ "is the vertical direction of bedding.

Table 2 Results of the crack test

Number	Lithology	Dimension		Total weight(g)	Flying distances(cm)			Crack kinetic energy (cm.g)
		Diameter (mm)	Length (mm)		5<r<11	11<r<24	r>24	
					Weight of fragments(g)			
MS01H	marble	48.2	10.1	481	19	1	12	31.5
MS01V		48.5	10.5	495	2	4	4	16
MS04H		48.3	10.6	487	8	19	11	24
MS04V		48.5	10.8	499	25	34	36	132
MS02H	Magnetite	48.2	10.6	801	170	7	69	120
MS02V		48.2	10.3	799	17	7	32	135.2
MS05H		48.1	10.8	792	18	14.5	80	118.4
MS05V		48.2	10.6	805	17	169	110	200.1
MS03H	Granite	48.2	10.3	503	16	17	27	24.5
MS03V		48.5	10.5	507	63	32	12	76.2
MS06H		48.2	10.8	509	28	86.2	20	213.2
MS06V		48.3	10.3	499	15	127	4	118.5

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 $(1-5) \times 10^{-6}$.

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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:

$$B = \sigma_c / \sigma_t \tag{3}$$

Where B is the intensity brittleness index; σ_c is compressive strength(Mpa); σ_t is tensile strength(Mpa).

The results are listed in Table 3, and intensity classification is as follow[3]:

$$\begin{cases} B \leq 10 & none \\ 10 < B \leq 14 & weak\ rockburst \\ 14 < B \leq 18 & medium\ rockburst \\ 18 < B & strong\ rockburst \end{cases} \tag{4}$$

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 Ku is defined by the equation:

$$K_u = U / U_l \tag{5}$$

Where U is the total deformation; U_l is permanent or plastic deformation. The intensity classification is[4]:

$$\begin{cases} K_u \leq 2.0 & none \\ 2.0 < K_u \leq 6.0 & weak\ rockburst \\ 6.0 < K_u \leq 9.0 & medium\ rockburst \\ 9.0 < K_u & strong\ rockburst \end{cases} \tag{6}$$

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:

$$W_{ET} = \Phi_{sp} / \Phi_{st} \tag{7}$$

Where W_{ET} is the elastic energy index; Φ_{sp} is the elastic deposited energy(KJ); Φ_{st} 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 tensity classification equation is:
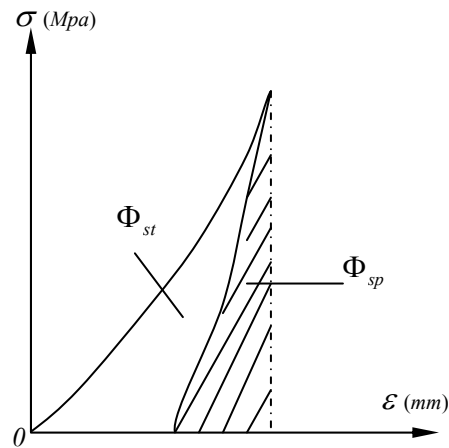

Fig.2 Test curves for elastic energy index

$$\begin{cases} W_{ET} < 2.0 & none \\ 2.0 \leq W_{ET} < 5.0 & medium\ rockburst \\ W_{ET} \geq 5.0 & strong\ rockburst \end{cases} \tag{8}$$

The energy ratio index (η) is defined in 1973 by Mo tycaka: η is the ratio of impact elastic energy(Φ_0), the equation is given by:

$$\begin{cases} \eta = (\Phi_k / \Phi_0) \times 100\% \\ \Phi_k = \sum_{i=1}^{n} \frac{1}{2} m_i v_i^2 \\ \Phi_0 = \frac{1}{2} \sigma_{max} \cdot \varepsilon_{max} \end{cases} \tag{9}$$

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; σ_{max} is the maximal stress; ε_{max} is the maximal elastic strain.

The critical classification equation is:

$$\begin{cases} \eta \leq 3.5\% & none \\ 3.5\% < \eta \leq 4.2\% & weak\ rockburst \\ 4.2\% < \eta \leq 4.7\% & medium\ rockburst \\ \eta > 4.7\% & strong\ rockburst \end{cases} \tag{10}$$

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 radio 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

Number	Depth(m)	B	Ku	WET	η(%)	Evaluation
MS01H	520	7.75	2.5	1.53	3.91	none
MS01V	520	7.5	2.3	1.42	3.23	none
MS02H	540	14.3	6.5	3.94	7.26	medium
MS02V	540	13.5	6.2	3.78	8.56	medium
MS03H	590	15.9	11.02	7.82	4.23	medium
MS03V	590	16.4	10.23	7.56	5.62	strong
MS04H	499	7.57	1.9	1.85	3.24	none
MS04V	499	7.8	1.7	1.82	9.12	weak
MS05H	580	14.5	7.6	5.12	8.22	weak
MS05V	580	13.7	7.5	5.23	11.24	weak
MS06H	610	20.3	12.1	8.23	15.32	strong
MS06V	610	19.4	11.06	8.17	10.51	strong

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:

$$\begin{cases} \sigma_{h(max)} = 0.82 + 0.0429H \\ \sigma_{h(min)} = 0.69 + 0.0285H \\ \sigma_v = 0.53 + 0.0311H \end{cases} \quad (11)$$

Where $\sigma_{h(max)}$ is the maximal horizontal principal stress, $\sigma_{h(min)}$ is the minimal horizontal principal stress, σ_v 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 (σ_θ) to the compressive strength (σ_c), researches have been shown that:

$$\begin{cases} T \leq 0.3 & none \\ 0.3 < T \leq 0.5 & weak\ rockburst \\ 0.5 < T \leq 0.7 & medium\ rockburst \\ T > 0.7 & strong\ rockburst \end{cases} \quad (12)$$

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

Table 4 The evaluation based on T index

Depth(m)	Rock Name	σθ(MPa)	σc(MPa)	T	Evaluation
499	Marble	27.6	56.8	0.486	Weak
520	Marble	34.9	58.5	0.597	Medium
540	Magnetite	58.2	116.4	0.505	Medium
580	Magnetite	56.2	110.3	0.515	Medium
590	Granite	69.9	120.6	0.582	Medium
610	Granite	89.9	126.3	0.712	Medium-Strong

From the data of T it has been shown: the magnetite and granite wall rock have the probability of medium rockburst, the marble wall rock have the probability of weak to medium rockburst.

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]:

$$W_e = 0.5(\sigma_1\varepsilon_1 + \sigma_2\varepsilon_2 + \sigma_3\varepsilon_3) \quad (13)$$

Where σ_1, ε_1, σ_2, ε_2, σ_3, ε_3 respectively is the principal stress and 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/m^3;

In the wall rock mass of the -520m level, the maximal elastic strain energy is 119.5kJ/m^3;

In the wall rock mass of the -540m level, the maximal elastic strain energy is 126.2kJ/m^3;

In the wall rock mass of the -580m level, the maximal elastic strain energy is 117.8kJ/m^3;

In the wall rock mass of the -590m level, the maximal elastic strain energy is 125.9kJ/m^3;

In the wall rock mass of the -610m level, the maximal elastic strain energy is 138.5kJ/m^3;

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As the theoretical study and field monitoring indicated, when the elastic strain energy is larger than $89kJ/m^3$, 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 educe 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 Chenchao 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.

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