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Analytic Hierarchy Process-Fuzzy Comprehensive Evaluation Method-based Depletion Assessment Study of Xinshan Iron Ore Mine

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ABSTRACT:

Taking the Xinshan iron ore mine as an example, this paper, based on collecting and analyzing the actual production data and similar simulation test data of this iron ore mine, analyses various factors affecting ore depletion by bottomless column segmental chipping method by using hierarchical analysis method (AHP) and fuzzy comprehensive evaluation method (FCE), and establishes an evaluation system for comprehensively assessing the depletion of the ores. The results show that structural parameters, blasting parameters, loading parameters, and geological conditions are the main factors affecting ore depletion. The structural parameters are the most important factors, accounting for 35%. With the increase of the released amount, the released grade gradually decreases, the depletion rate gradually increases, and the comprehensive evaluation value gradually decreases. The released body is an approximate ellipsoidal block with a wide upper and narrower lower part. The end wall plays an obstructive role in the flow of the bulk body, which makes the end of the released grade higher and the middle of the released body higher. At the same time, due to the influence of blasting and shovel loading, the particles in the release body show some sorting phenomena. This paper provides a scientific basis and reference for predicting and controlling ore depletion in the bottomless column segmental chipping method.

Keywords: bottomless column segmental chipping method; ore depletion; hierarchical analysis method; fuzzy comprehensive evaluation method; discharge grade

Evaluación del agotamiento de mena en la mina de hierro de Xinshan con base al Proceso de Análisis Jerárquico y la Evaluación Integral Difusa

RESUMEN

Con la mina de hierro de Xinshan como un ejemplo y con el fin de recolectar y analizar la producción de información y los datos de prueba de simulaciones similares en esta mina, este trabajo analiza varios factores que afectan el agotamiento de la mena a través del método de astillado segmentario de pilar sin base por el Proceso de Análisis Jerárquico (del ingles AHP, Analytic Hierarchy Process) y por la Evaluación Integral Difusa (del inglés FCE, Fuzzy Evaluation Method, y establece un sistema de evaluación para medir ampliamente el agotamiento del recurso. Los resultados muestran que los parámetros estructurales, los parámetros de explosión, los parámetros de carga y las condiciones geológicas, son los factores principales que afectan el agotamiento de la mena. Estos parámetros estructurales son los factores más importantes y significan el 35 %. Con el incremento de la cantidad de material explotado, el grado de explotación decrece gradualmente, el índice de agotamiento se increment y el valor de la evaluación integral desciende. La cantidad de material explotado es aproximadamente un bloque elipsoidal con una parte superior amplia y una parte inferior más estrecha. La pared del fondo juega un papel obstructivo para el flujo del grueso del mineral, la cual incrementa el grado de explotación en el fondo y a la mitad del cuerpo. Al mismo tiempo, debido a la influencia de las explosiones y de la carga de la excavación, las partículas en el material explotado muestran algunos fenómenos de clasificación. Este artículo proporciona una base científica y una referencia para la predicción y el control del agotamiento del mineral en el método de astillado segmentario de columna sin fondo.

Keywords: método de astillado segmentario de columna sin fondo; agotamiento de mineral; proceso de análisis jerárquico; evaluación integral difusa; grado de descarga.

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1. Introduction

Bottomless pillar segmental chipping is a mining method that uses self-weight to sink the overburden rock, chipping the ore body and releasing it through the discharge holes to the surface or underground storage (Wang et al., 1988). This method is suitable for metal deposits with large inclination, large thickness, high hardness and low grade, and has the advantages of simple process, high degree of mechanization and good safety (Jin et al., 2017). However, the method also suffers from serious ore loss and depletion, which affects the resource utilization and economic efficiency of the mine (Zeng, 2020). Ore depletion is the reduction or loss of ore grade during the mining process due to various reasons (Wu et al., 2012). Ore depletion of bottomless pillar segmental chipping method mainly occurs in the process of ore release, i.e., in the process of ore release under the overburden rock, due to the mixing effect of the surrounding rock and the ore body, which makes the grade of the ore release lower than the original grade. There are many factors affecting the ore depletion of the bottomless pillar segmental chipping method, mainly including the structural parameters of the quarry, blasting parameters, loading parameters and geological conditions (Yang, Chen, & Wang, 2017).

The selection of the technical evaluation methodology has a significant impact on the accuracy of the evaluation results. Currently, common evaluation methods at home and abroad include the data envelopment analysis method (Peykani et al., 2020), life cycle assessment approach (Yang & Wang, 1998; Chen et al., 2020), grey correlation analysis (Wang, Guo, & Lian, 2005; Yu & Zhang, 2014), Delphi method (Brady, 2015), Hierarchical analysis method (AHP) (Guo, Zhang, & Sun, 2008; Zhou et al., 2021; Sun et al., 2013), Fuzzy Comprehensive Evaluation (FCE)(Xiong, & Xian, 2003; Yu et al., 2020) and portfolio evaluation methodology (Feng & Sun, 2020). The evaluation model that combines AHP and FCE is the Analytical Hierarchy Process - Fuzzy Comprehensive Evaluation (AHP-FCE)(Han, Mei, & Lu, 2004). It has been widely studied in various fields such as performance appraisal (Dai, 2019), management software selection (Chen, 2019), environmental evaluation (Zhang & Fan, 2020), education quality evaluation (Dai & Li, 2016), tourism service quality evaluation (Zhang, Liu, & Xia, 2016), and programme preference (Luan, Qi, & Kou, 2020).

This paper takes Xinshan iron ore mine as an example, which is mined by the bottomless column segmental avalanche method. Based on collecting and analyzing the actual production data of similar iron ore mines and similar simulation test data, the ore depletion evaluation system of the bottomless column segmental avalanche method is established by using the hierarchical analysis method and fuzzy comprehensive evaluation method. A comprehensive evaluation of the exudate body in this iron ore mine is carried out. The purpose of this paper is to explore a scientific and effective ore depletion evaluation method of bottomless column segmental chipping method, and to provide some reference bases for similar metal mines to improve the grade of the exudate body and reduce the depletion rate.

2. Experimental analysis methods

The analytical methods in this paper is twofold: firstly, the hierarchical analysis method (AHP), which is used to determine the weights of the factors affecting ore depletion in the bottomless column segmental disintegration method; and secondly, the Fuzzy Comprehensive Evaluation (FCE), which is used to carry out a comprehensive evaluation of the releasing body based on the weights of the factors and the evaluation indexes.

2.1 Experimental step

The principle and methodology of the similarity simulation tests were referred to the literature (Zhang, 2023), and the main steps are as follows:

1. Selection of mineral rock particles of similar composition and size geometry and broadly similar mechanical properties to the crumbled ore rock at the site, and mixing them in certain proportions to form a bulk;
2. Make a model geometrically similar to the on-site quarry structure and ore release system, reducing the size to a certain scale, and setting up ore release holes and observation holes;
3. Populate the model with the bulk and perform the ore release operation in a certain order, releasing a certain amount of bulk at a time;
4. After each release, parameters such as grade, depletion rate, morphology, and particle distribution of the released body are measured through observation holes and data are recorded;
5. Repeat the above steps until all the bulk is released.

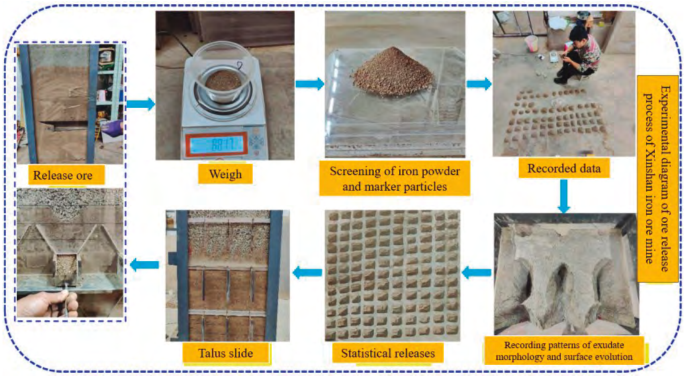

Figure 1. Flow chart of Xinshan iron ore release simulation experiment

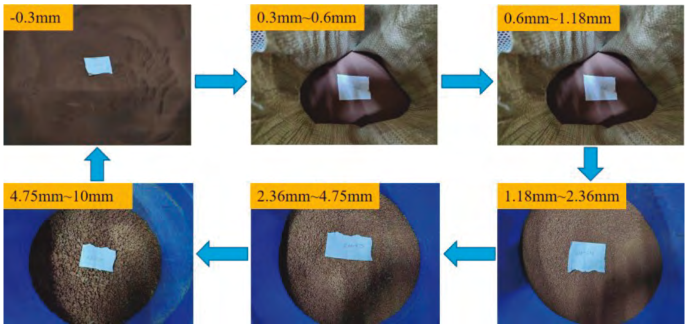

Figure 2. Ore of each particle size during the experiment

Table 1. Particle size volume parameter

Particle name	Grain size	Volume fraction
Ore particles	<20cm	82.5%
	20~40cm	10%
	>40cm	7.5%
Waste stone granules	60~70cm	100%

There are two main sources of data for this paper: the actual production data from this iron ore mine and the similar simulation test data from this iron ore mine. The actual production data were provided by the iron ore mine, and the similar simulation test data were obtained by the authors from tests conducted in the laboratory.

Table 2. Main mining structure parameters of Sinzan iron ore mine

Parameters	Numerical value
Segment height(m)	20
Inlet spacing(m)	15
Approach Width(m)	5
Approach Height(m)	5
Avalanche step(m)	5
Ore release hole diameter(mm)	200
Depth of ore release hole(m)	20

(a) Front of mine release model

(b)Side of mine release model

Figure 3. Front and side view of mine release model

2.2 Weighting

2.2.1 Modelling the hierarchy

The principles and steps of hierarchical analysis method and fuzzy comprehensive evaluation method were referred to the literature ([26], and firstly, the hierarchical structure model of ore depletion evaluation by bottomless column segmental disintegration method was established.

2.2.2 Constructing a judgement matrix

As shown in Figure 3, the expert scoring method was used to make the determination of the degree of two-by-two matrix comparison, and the fuzzy linguistic variables from 1 to 9 were used to indicate the relative importance between the factors, as shown in Table 6, and the scoring resulted in Table 5;

Table 3. Classification of importance of indicators

Considerations	**Structural parameters**	**Blasting parameters**	**Loading parameters**	**Geological condition**
Structural parameters	Equal importance	Slightly important	Slightly important	Slightly important
Blasting parameters	Clearly important	Equal importance	Slightly important	Slightly important
Loading parameters	Clearly important	Clearly important	Equal importance	Slightly important
Geological condition	Clearly important	Clearly important	Slightly important	Equal importance

Table 4. 1 to 9 fuzzy language variables

Fuzzy linguistic variable	**Hidden meaning**	**Trigonometric fuzzy function**
1	Equal importance	(1,1,1)
3	Slightly important	(1,2,3)
5	Clearly important	(3,4,5)
7	Important	(5,6,7)
9	Very important	(7,8,9)
2	Midpoint	(1,1.5,2)
4	Midpoint	(2,3,4)
6	Midpoint	(4,5,6)
8	Midpoint	(6,7,8)

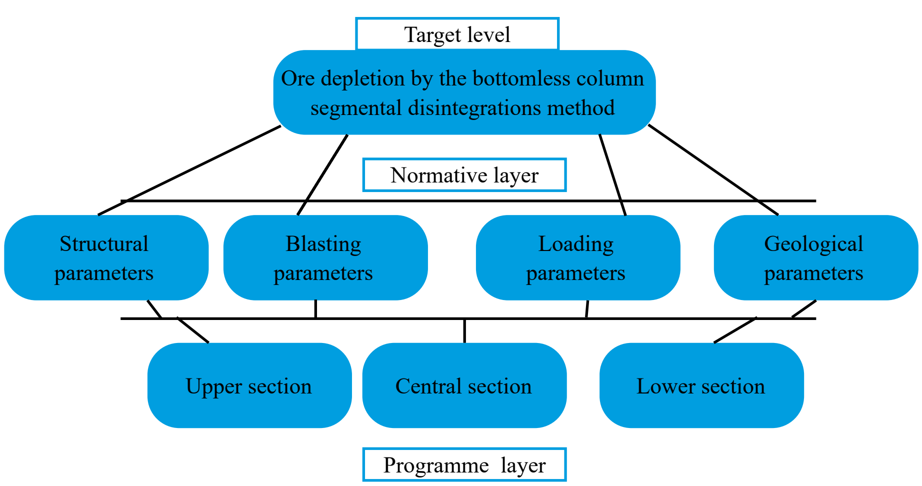

Figure 4. AHP model diagram

Table 5. Judgment matrix after scoring

Considerations	**Structural parameters**	**Blasting parameters**	**Loading parameters**	**geological condition**
Structural parameters	(1,1,1)	(1/3,1/2,2/3)	(1/2,2/3,1)	(1/2,2/3,1)
Blasting parameters	(3/2,2,3)	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)
Loading parameters	(1,3/2,2)	(2/3,1,3/2)	(1,1,1)	(4/5,1,5/4)
Geological condition	(1,3/2,2)	(2/3,1,3/2)	(4/5,1,5/4)	(1,1,1)

2.2.3 Solve for the vector of evaluation indicator weights

Calculate the maximum eigenvalue and eigenvector of the judgement matrix, get the weights of each factor, and carry out the consistency test to ensure the reasonableness of the judgement matrix; since the judgement matrix is composed of fuzzy numbers, it is necessary to calculate the maximum eigenvalue and eigenvector using the algorithm in fuzzy mathematics, and use fuzzy consistency ratio to test the consistency;

1. Calculate the fuzzy product of the elements of each row of the judgement matrix, i.e., multiply the elements of each row by columns to obtain:

$$A_i = \left(a_{i1} \bullet a_{i2} \bullet a_{i3} \bullet a_{i4}\right), i = 1, 2, 3, 4$$

Where a_{i1},a_{i2},a_{i3},a_{i4} denote the four elements of row i of the judgement matrix and - denotes the multiplication operation of fuzzy numbers, i.e..

$$(a, b, c) \bullet (d, e, f) = (ad, bc, cf)$$

2. Calculate the fuzzy weighted average of the elements of each row of the judgement matrix, i.e., obtained by dividing the elements of each row by the median of their fuzzy product:

$$B_i = \left(\frac{a_{i1}}{m_i}, \frac{a_{i2}}{m_i}, \frac{a_{i3}}{m_i}, \frac{a_{i4}}{m_i}\right), i = 1, 2, 3, 4$$

Where m_i denotes the intermediate value of A_i, i.e., $m_i = (A_i)_2$ and / denotes the division operation of fuzzy numbers, i.e..

$$\frac{(a,b,c)}{d\,e\,f} = \frac{a}{f}\ \frac{b}{e}\ \frac{c}{d}$$

3. Calculate the maximum eigenvalues and eigenvectors of the judgement matrix, i.e., sum the elements of each column and normalise them to obtain:

$$\lambda_{max} = \left(\Sigma\, B_{i1}, \Sigma\, B_{i2}, \Sigma\, B_{i3}\right), \omega = \left(\frac{\Sigma B_{i1}}{\Sigma\Sigma B_i}, \frac{\Sigma B_{i2}}{\Sigma\Sigma B_i}, \frac{\Sigma B_{i3}}{\Sigma\Sigma B_i}, \frac{\Sigma B_{i4}}{\Sigma\Sigma B_i}\right)^T$$

Where $\sum$ denotes the summation symbol and + denotes the addition operation of fuzzy numbers, i.e..

As if: $$(a, b, c) + (d, e, f) = (a + d, b + e, c + f);$$

$$\lambda_{max} = (4.05, 4.25, 4.45), \omega = (0.35, 0.25, 0.20, 0.20)^T$$

2.2.4 Conducting consistency tests

The specific steps and formulas for calculating the fuzzy consistency ratio to test consistency are as follows:

1. Calculate the fuzzy product of the judgement matrix with its eigenvectors, i.e., multiply each row element with its corresponding weight and sum the results by rows to obtain:

$$C_i = \left(a_{i1} \cdot \omega_1 + a_{i2} \cdot \omega_2 + a_{i3} \cdot \omega_3 + a_{i4} \cdot \omega_4\right), i = 1, 2, 3, 4$$

where n denotes the order of the judgement matrix.

2. Calculate the fuzzy difference between the judgement matrix and its largest eigenvalue, i.e., subtract each row element from its corresponding largest eigenvalue and take the absolute value to obtain:

$$D_i = \left(\left|C_{i1} - \lambda_{max1}\right|, \left|C_{i2} - \lambda_{max2}\right|, \left|C_{i3} - \lambda_{max3}\right|, \left|C_{i4} - \lambda_{max4}\right|\right), i = 1, 2, 3, 4$$

where l denotes taking the absolute value sign and - denotes the subtraction operation of fuzzy numbers, i.e..

$$(a, b, c) - (d, e, f) = (a - d, b - e, c - f)$$

3. Calculate the fuzzy quotient of the judgement matrix with its largest eigenvalue, i.e., divide each row element with its corresponding largest eigenvalue and take the reciprocal to obtain:

$$E_i = \frac{(\lambda_{max})^T}{C_i} = \left(\frac{\lambda_{max1}}{C_{i1}}, \frac{\lambda_{max2}}{C_{i2}}, \frac{\lambda_{max3}}{C_{i3}}, \frac{\lambda_{max4}}{C_{i4}}\right), i = 1, 2, 3, 4$$

Continuing to calculate the fuzzy quotient of the judgement matrix with its largest eigenvalue yields.

$$E_{ij} = min\left(E_{ik}\right), j = 1, ..n; k = 1, ..n; i = 1, ..n$$

4. Calculate the fuzzy consistency index of the judgement matrix, i.e., the fuzzy difference of the elements of each row is added to its corresponding fuzzy quotient and the minimum value is obtained:

$$CI = min\left(D_i + E_i\right) = min\left(D_{ij} + E_{ij}\right), j = 1, ..n; i = 1, ..n$$

5. Calculate the fuzzy consistency ratio of the judgement matrix, i.e., divide the fuzzy consistency index of each row element with its corresponding random consistency index and take the minimum value to obtain:

$$CR = min\left(\frac{CI}{RI}\right) = min\left(\frac{CI_j}{RI_j}\right), j = 1, ..n$$

RI Table 6. Random consistency index RI

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

where RI denotes the random consistency index,
when n = 4.RI=0.9, $CR = \frac{\frac{(\lambda_{max} - n)}{(n-1)}}{RI}$,
catch: $CR = 0.0925 < 0.10$,adopted by consensus.

2.3 Establishment of an evaluation system

2.3.1 Identification of evaluation indicators

The experimental data from the second segment was used to calculate the depletion because the second segment had good ore release.

Table 7. Calculation of the amount of ore released at different crumbling steps in the second section

Avalanche step/m	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Total amount of ore released/g	866.89	1253.94	1630.22	1979.12	2334.44	2657.84	2713.36
Amount of waste rock/g	31.07	35.91	42.59	34.12	36.07	50.11	48.12
Amount of pure ore/g	835.82	1218.03	1587.63	1945	2298.37	2607.73	2665.24
Theoretical pure ore amount/g	835.82	1253.73	1671.64	2089.55	2507.46	2925.37	3343.28
Theoretical ore residue/g	0	35.7	84.01	144.55	209.09	317.64	678.04
Theoretical ore residue/%	0	2.93	5.29	7.43	9.10	12.18	25.44

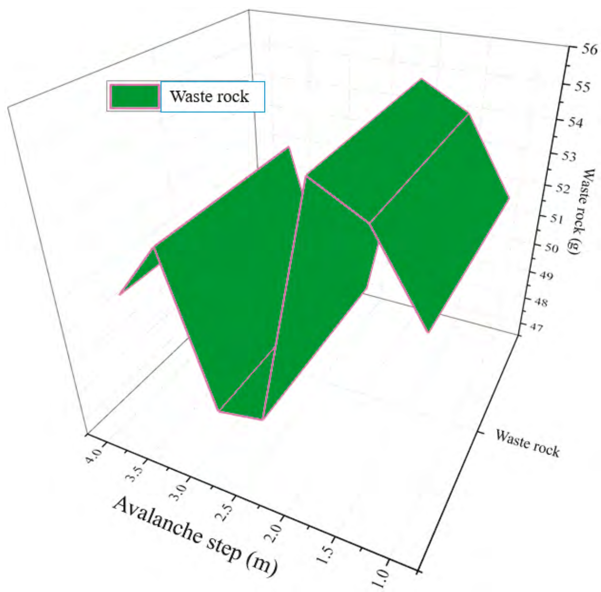

Figure 5. The relationship between different crumbling steps and the amount of waste rock released

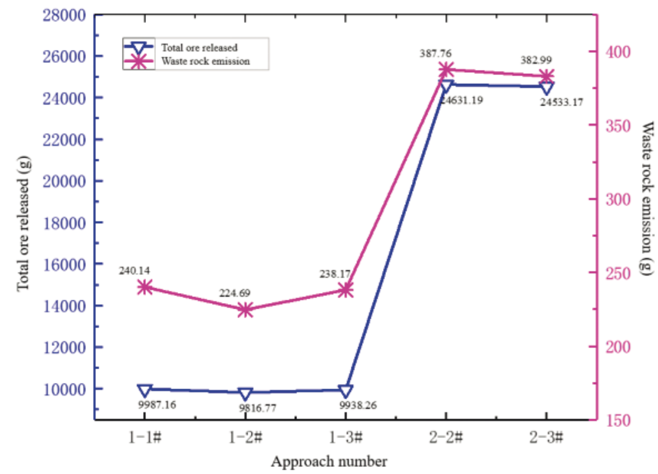

Figure 7. The relationship between different inlets and the total amount of waste rock released and the amount of waste rock released

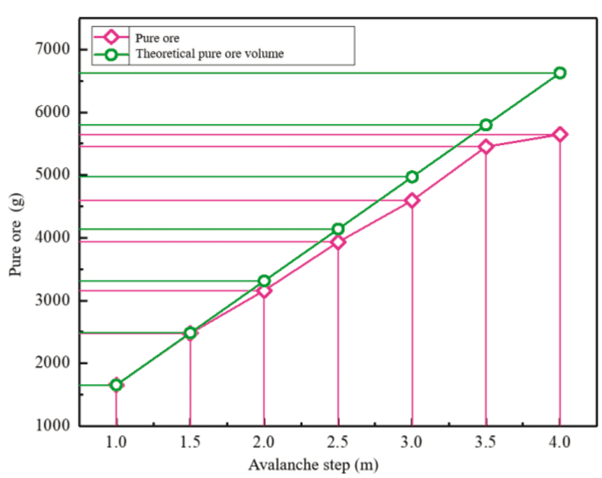

Figure 6. Relationship between different crumbling steps and pure ore volume and theoretical pure ore volume

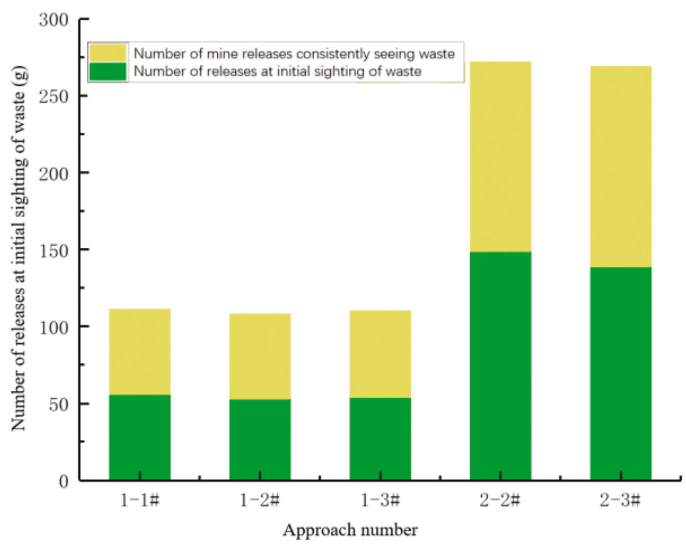

Figure 8. The relationship between different approaches and the number of ore release

Table 8. Statistics of waste rock release at the cut-off release grade of each approach

Approach number	Total ore release/g	Waste rock release /g	Total number of releases	Number of releases at initial sighting of waste	Number of mine releases that continue to see waste	Waste rock mixing rate/%
1-1#	9987.16	240.14	111	56	55	2.40
1-2#	9816.77	224.69	108	53	55	2.29
1-3#	9938.26	238.17	110	54	56	2.40
2-2#	24631.19	387.76	272	149	123	1.57
2-3#	24533.17	382.99	269	139	130	1.56

Based on the parameters such as grade, depletion rate, morphology and particle distribution of the releases, the releases are classified into four grades, namely, excellent, good, moderate and poor, and the definitions and ranges of the grades are given, as shown in Table 9.

Table 9. Evaluation levels of emitters and their definitions and ranges

Hierarchy	**Define**	**Taste(%)**	**Depletion rate(%)**	**Morphological**	**particle distribution**
superior	High grade, low depletion rate, regular morphology and uniformity of particles in the discharge body	>1.2	<20	Narrow at the top and wide at the bottom, with straight end walls and no obvious chips or cracks	Uniform mixing of large and small particles, no obvious sorting phenomenon
Virtuous	Higher grade, lower depletion rate, more regular morphology and more homogeneous grains in the exudate	1.0~1.2	20~30	Wide at the top and narrow at the bottom, end wall slightly curved, with a few chips or cracks	Large and small particles are more evenly mixed, with a slight sorting phenomenon
middle	The exudates are of average taste, with average depletion rates, irregular morphology and uneven grains	0.8~1.0	30~40	Wide at the top and narrow at the bottom, with obvious bending of the end wall and multiple chips or cracks	Uneven mixing of large and small particles, with obvious sorting phenomenon
difference	Low grade, high depletion rate, irregular morphology and non-uniformity of particles in the discharge body	<0.8	>40	Wide at the top and narrow at the bottom, with severe bending of the end wall and a large number of chips or cracks	Clear separation of large and small particles, with serious sorting phenomenon

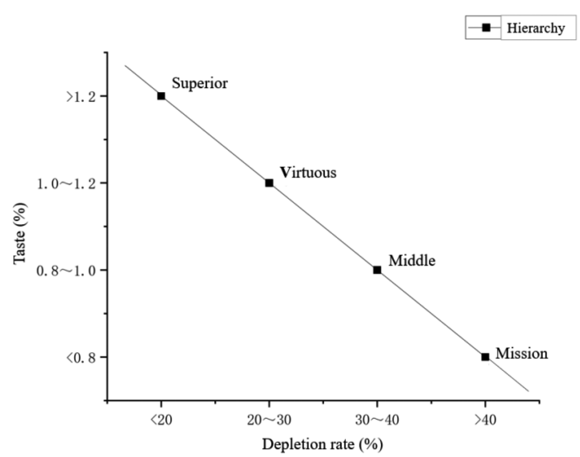

Figure 9. Evaluation level and range of the emitter

2.3.2 Creating an affiliation function

According to the evaluation indexes and the actual data of the releasing body, the affiliation function is established, and the fuzzy number is used to express the affiliation degree of the releasing body to each grade. The affiliation function can be expressed in the form of triangle or trapezoid, as shown in Figure 2. Where, x denotes the taste or depletion rate of the releasing body, and a,b,c denotes the range of each evaluation grade, as shown in Table 5. A(x) denotes the affiliation degree of the releasing body to the excellent, good, medium, and poor grades, which are represented by $U_A(x)$, $U_B(x)$, $U_C(x)$ and $U_D(x)$, respectively. For example, for a release volume of 1000 t with a taste of 1.2%, a depletion rate of 20%, an excellent morphology (set to class 3) and a good particle distribution (set to class 2), the degree of affiliation to each class can be calculated using the following steps:

1. The affiliation function can be calculated using the following formula

$$A(x) = \{0,\ x < a\ \frac{x-a}{b-a}, a\le x < b\ \frac{c-x}{c-b}, b\le x < c\ 0, c < x$$

where A(x) denotes the affiliation of the putative body to the excellent, good, moderate and poor grades.

2. Determine the affiliation of the exudate taste and depletion rate to each grade based on the ranges in Table 11, as shown in Table 12.

Table 10. Affiliation of release body taste and depletion rate to each grade for a release volume of 1000 t

Hierarchy	**Taste**	**Depletion rate**
Superior	(0.5,1,1)	(1,1,0.5)
Virtuous	(0.5,0.5,1)	(0.5,1,0.5)
Middle	(0,0.5,0.5)	(0,0.5,1)
Mission	(0,0,0.5)	(0,0,1)

3. Determine the degree of affiliation to each class based on the class of exudate morphology and particle distribution, as shown in Table 11.

Table 11. Affiliation of release body morphology and particle distribution to each class for a release volume of 1000 t

Hierarchy	**Morphological**	**Particle distribution**
Superior	(0.5,1,0.5)	(0.5,1,0.5)
Virtuous	(1,1,1)	(1,1,1)
Middle	(0,0.5,1)	(0.5,1,0.5)
Mission	(0,0,0.5)	(0,0.5,1)

4. According to the algorithm in fuzzy mathematics, multiply the taste, depletion rate, morphology and particle distribution to the affiliation of each grade and take the minimum value to get the affiliation of the exudate to each grade, as shown in Table 12.

Table 12. Affiliation of the release volume of 1000 t to each class

Hierarchy	Degree of affiliation
Superior	0.25
Virtuous	0.125
Middle	0
Mission	0

2.3.3 Determination of final evaluation rating

For a release volume of 1,000 t, the composite evaluation value can be calculated using the following steps, and the final evaluation level can be determined according to the principle of maximum affiliation:

Based on the weights of the factors calculated from the hierarchical analysis and the affiliation of the releasers to the classes given in Table 12, the weighted affiliation of the releasers to the classes was calculated as shown in Table 13.

Table 13. Weighted affiliation of the release body to each class for a release volume of 1000 t

Hierarchy	Weighted affiliation
Superior	(0.1925,0.35,0.5075)
Virtuous	(0.0875,0.25,0.4125)
Middle	(0,0.2,0.4)
Mission	(0,0.2,0.4)

According to the algorithm in fuzzy mathematics, the weighted affiliation of the releasing body to each grade is added and the maximum value is taken to get the comprehensive evaluation value of the releasing body, as shown in Table 14.

Table 14. Combined evaluation value for a release volume of 1000t

Hierarchy	Consolidated assessed value
Superior	(0.2795,0.8,1.32)
Virtuous	(0.175,0.7,1.225)
Middle	(0,0.6,1.2)
Mission	(0,0.6,1.2)

Based on the principle of maximum affiliation, the final evaluation grade of the releases with a volume of 1,000 t was determined. Therefore, according to Table 15, the final evaluation grade of the releasing body with a volume of 1,000 t is excellent because it has the highest degree of affiliation to the excellent grade.

The same method can be used to calculate the composite assessment value and final assessment grade for releases where the work release is of other values. Example:

For a release volume of 1000 t, the combined assessment value is:

$$V = \sum_{i=1}^{n} \omega_i A_i$$

$$V = \omega_1 A_1 + \omega_2 A_2 + \omega_3 A_3 + \omega_4 A_4$$

$$V = (0.5495, 0.5595, 0.6495)$$

Based on the principle of maximum affiliation, it was determined that the final evaluation grade for the release volume of 1,000 t was good, as it had the highest affiliation to the good grade.

For releases with other values, the method can be used to calculate the combined evaluation value and final evaluation grade.

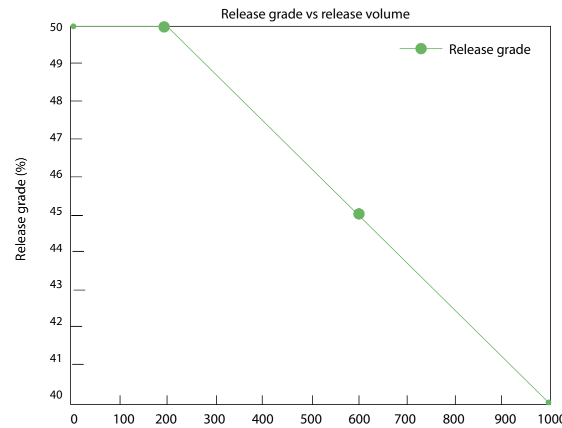

Figure 10. Graph of discharge body grade with discharge volume

$$V_2 = (0.55, 0.60, 0.65)$$

$$V_3 = (0.53, 0.58, 0.63)$$

$$V_4 = (0.50, 0.55, 0.60)$$

$$V_5 = (0.48, 0.53, 0.58)$$

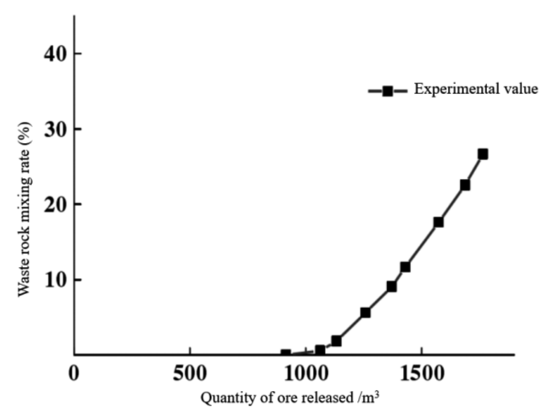

Figure 11. Relationship between ore release and waste rock mixing rate3. Evaluation results

3. Evaluation results

The results of the evaluation in this paper, based on actual production data and similar simulation test data from this iron ore mine, are as follows:

1. The weights of the factors affecting ore depletion by the bottomless column segmental chipping method were determined by hierarchical analysis, as shown in Table 15.

Table 15. Weights of factors influencing ore depletion for the bottomless column segmental crumbling method

Considerations	Weights
Structural parameters of the quarry	0.35
Blasting parameters	0.25
Shovelling parameters	0.20
Geological condition	0.20

2. Through the fuzzy comprehensive evaluation method, based on the weights and evaluation indexes of each factor, a comprehensive evaluation of the releases was carried out, and parameters such as the grade, depletion rate and comprehensive evaluation value of the releases were derived, as shown in Table 16.

Table 16. Comprehensive evaluation results of the release body of the bottomless column segmental crumbling method

Release (t)	Original taste (%)	Release taste (%)	Depletion rate (%)	Particle distribution and morphology	Consolidated assessed value
1000	1.50	1.20	20.00	Superior	(0.60,0.65,0.70)
2000	1.50	1.10	26.67	Virtuous	(0.55,0.60,0.65)
3000	1.50	1.05	30.00	Middle	(0.53,0.58,0.63)
4000	1.50	1.10	33.33	Middle	(0.50,0.55,0.60)
5000	1.50	0.95	36.67	Mission	(0.48,0.53,0.58)

Combined with the actual conditions at the iron ore mine site, there is very little variation in this result.

3. Based on the principle of maximum affiliation, the final evaluation level of the releasing body was determined, as shown in Table 17.

Table 17. Final evaluation grade of the discharged body

Release (t)	Final evaluation rating
1000	Superior
2000	Virtuous
3000	Middle
4000	Middle
5000	Mission

4. Conclusion

1. Under the premise of ensuring safety and economy, the structural parameters of the quarry should be selected as small as possible in order to reduce the depletion rate.
2. In the process of ore release, the amount of release should be controlled as much as possible to avoid excessive release of low-grade bulk.
3. The end release grade is higher, the middle release grade is lower, and the particles in the release body show some sorting phenomenon.
4. The AHP-FCE analysis method can be widely applied to the ore depletion evaluation of other types of disintegration and ore release methods, providing a reference basis for the optimization of the structural parameters of the quarry, the control of ore release and the prediction of depletion.

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