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Study on process mineralogy and iron separation technology by step milling-magnetic separation

The main mineral in the iron ore from Hubei was poor magnetite, it has fine granularity and low iron grade. The content of total iron (TFe) in the original ore is from 12% to 20%, and the content of magnetic iron (MFe) was from 6% to 13%. Through the process mineralogy research, crushing product sieving, magnetic analysis and grinding granularity test, the iron ore products with an iron concentrate grade of 68.84% and an iron recovery rate of 72.87% can be obtained. In the study, it was found that the iron grade of the original ore and the magnetic iron (MFe) were 12.11% and 16.34% respectively. The iron grade of ore size of -0.074 mm was low in negative cumulative and positive cumulative analysis. The iron recovery rate was relatively low, i.e., 57.89%, this was due to that 19.89% of the ferric silicate in the sample of the raw ore cannot be recovered. Through dry magnetic separation, the iron grade can be raised to about 2.18%.

Keywords: *Poor magnetite; iron grade; magnetic analysis; iron selection test; iron recovery rate; dry magnetic separation.*

1. Introduction

In recent years, the output of crude steel [1] and the import of iron ore [2] have increased steadily in our country, the imports have ranked first in the world for many years. The demand of steel was increasing gradually, which puts forward to higher requirements for the fine processing of iron ore [3]. At present, there were many problems with iron ore stored in China, such as iron ore mining and metallurgy [4] were difficult, the comprehensive utilization rate of iron [5] was low, and the self-sufficient rate of iron ore in iron and steel industry was less than 50%. These factors provide a great challenge to the safety of China's economic operation and also provide a broad space for the development of iron ore resources for private enterprises. The grade of a certain iron ore in Hubei was low, it belongs to low grade magnetite ore [6]. The particle size of iron minerals was very small, the content of total iron (TFe) in the ore was generally from 12% to 20%, and the content of magnetic iron (MFe) was from 6% to 13%.

The main mineral in the iron ore from Hubei was poor magnetite and it needs to be processed. At present, limonite was mainly treated by gravity beneficiation, magnetization roasting-magnetic separation and magnetic separation-flotation combination [7-9]. Many domestic scholars have carried out research on this. Wanfeng Liu et al. use shaker re-election-flotation combined process to select iron [10]. Qiang Deng et al. use magnetization roasting-grinding classification-fine grain weakening-coarse grain to re-weak weakening [11], the iron ore concentrate with an iron grade of 61.22% and a recovery rate of 77.82% was obtained. According to the characteristics of high phosphorus oolitic hematite, Yang Dawei et al. carried out a series of experiments on iron-raising and phosphorus-reducing concentrates with reverse flotation, high-intensity magnetic separation, high-intensity magnetic separation-reverse flotation, reduction roasting-low-intensity magnetic separation and other schemes [12-14]. Finally, iron concentrates with iron grade of 92.34% and iron recovery of 90.31% were obtained. In foreign countries, fine-grained weak magnetic limonite was selected by flocculation-magnetic separation process [15], and high sorting efficiency and sorting index were obtained.

In view of the characteristics of low ore yield and low grade of magnetite ore in Hubei. In this study, we adopt the step milling-magnetic separation technology for iron selection research [16], which points out the direction for further development of the iron ore resources and provides early technical support for future beneficiation test and industrial production.

2. Ore properties

2.1 Chemical Composition Analysis and the Proportion of each Substance

The results of X-ray fluorescence spectrum analysis of the original ore are shown in Table 1. The main components of

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TABLE 1 X-RAY FLUORESCENCE SPECTRUM ANALYSIS RESULTS (%)

Chemicalcomposition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	SO_3
Content	42.07	25.69	15.78	0.8	1.08	6.51	0.65	4.24	0.03
Chemical composition	P_2O_5	MnO	Rb_2O	SrO	Y_2O_3	ZrO_2	BaO	Loss of burning	
Content	0.19	0.01	0.02	0.01	0.01	0.03	0.1	2.8	

TABLE 2 THE RESULTS OF CHEMICAL ELEMENT ANALYSIS OF RAW ORES (%).

Element	TFe	MFe	CaO	MgO	SiO_2	Al_2O_3	TiO_2	P	S
Content	16.34	12.11	0.83	1.05	42.23	25.57	4.12	0.085	0.047

the ore were Fe_2O_3, SiO_2 and Al_2O_3, their contents were 15.78%, 42.07% and 25.69% respectively. The other components were less, and the content of TiO_2 was 4.24%. These four components were very important for iron recovery, and other components were almost negligible. At the same time, the content of P_2O_5 is only 0.19%, and the phosphorus content of the ore was less, which indicates that the quality of the iron ore concentrate will be better.

The results of chemical element analysis of the original ore are shown in Table 2. The analysis of chemical elements in the ore includes total iron grade (TFe), magnetic iron (MFe), SiO_2 and Al_2O_3, and their contents were 16.34%, 12.11%, 42.23% and 25.69% respectively. The contents of CaO and MgO were 0.83% and 1.05% respectively and the contents of phosphorus (P) and sulfur (S) were 0.085% and 0.048%

2.2 MINERAL COMPOSITION AND CONTENT

The main mineral composition and content of the ore are shown in Table 3. The main metal minerals in the ore were magnetite, it also has ilmenite (plate titanite) and a small amount of red brown iron minerals. Occasionally, the porphyrite was randomly distributed in slate or schist. The main gangue minerals in the ore were sericite, followed by minerals such as zoisite or brown pebbles, quartz, and a small amount of argillaceous minerals distributed in the fine-grained or fine-grained band in the sericite interstitial space. The mineral contents of magnetite and sericite exceed 80%.

2.3. EMBEDDING CHARACTERISTICS OF MAJOR METAL MINERALS IN ORE

The main metal minerals of the ore were disseminated in the form of medium-fine particles, magnetite accounts for the main part. Among them, ilmenite-brookite was slightly disseminated, and partially densely immersed in elliptical plaques. The content of metal mineral was approximately 15% and the following was an introduction about major metal minerals:

Magnetite (Mt)

Magnetite of different particle sizes [17] are shown in Fig.1. The content of magnetite ranges from 13% to 25%, which was self-shaped medium-fine particles and distributed in schist or slate. Magnetite was also distributed in feldspar or quartz cracks, slightly banded, mostly in octahedron or rhombohedral dodecahedral shape. And hematite was often intergranulated or intergranular, its particle size was mostly between 0.05 and 0.7 mm and the maximum was approximately 1.2 mm. The aggregate of magnetite and hematite symbiosis in ore was fine-grained, and it was difficult to dissociate from gangue.

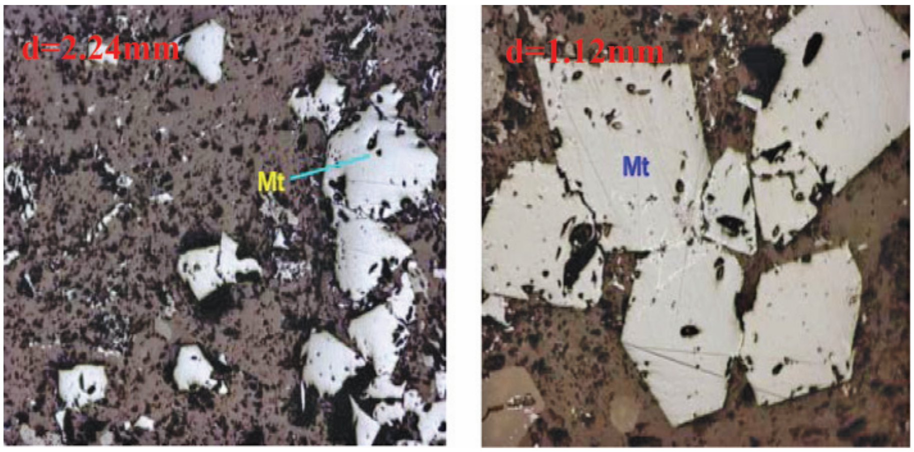

Fig.1. Magnetite of different particle sizes

Ilmenite (Ilm)

Ilmenite of different particle sizes are shown in Fig.2. The content of ilmenite ranges from 1% to 3%, which was a plate-like, evenly distributed along the slab or the ridge, and the strips or irregular hematite were usually distributed in the grains [18]. In the platy ilmenite crystallites, fine lamellar-like strips of hematite were distributed along the long axis, forming a solid solution separation structure, or a hematite fine vein distributed in the micro-cracks in the vertical long axis direction, including some ilmenite. The ore was distributed among the magnetite grains and it often coexists with brookite. The long particle size was between 0.01 and 0.15 mm and the maximum was approximately 0.2 mm.

Brookite (Bro)

Brookite of different particle sizes are shown in Fig. 3. The content of brookite ranges from 1% to 2%, and the thin plate

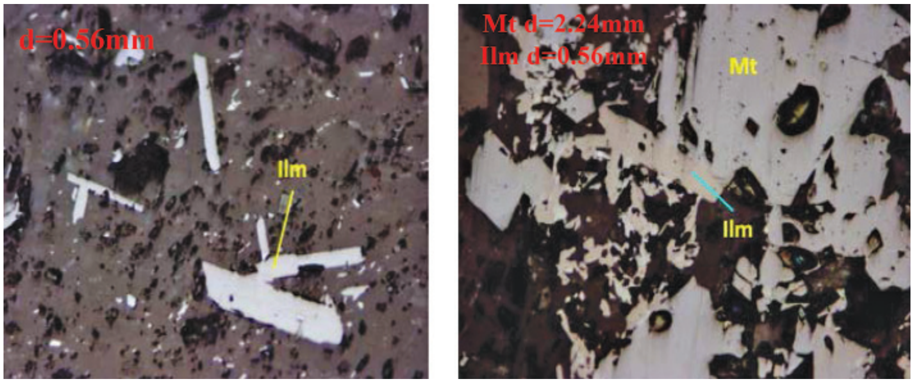

Fig.2 Ilmenite of different particle sizes

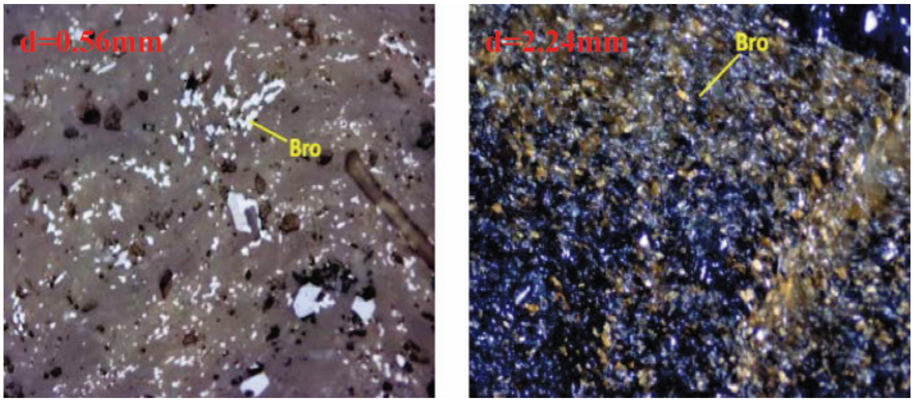

Fig.3 Brookite of different particle sizes

was columnar, short column or curved strip, evenly it distributed along the lamella or slab. It has a certain directionality, which was mixed with sericite, or symbiotic with ilmenite. And it was cut through magnetite or along the feldspar fissure [19]. The long particle size was between 0.005 and 0.1 mm.

Hematite (Hem)

Hematite of different particle sizes are shown in Fig. 4. The content of hematite was less, and it was mostly in the form of fine flat or leaf-like distribution in ilmenite, or it was distributed in the shape of needles and acicular [20]. Both of them form a solid solution separation structure or titanium, the micro-cracking of iron ore was replaced by vein-like interstitial, and the hematite was closely related to the magnetite. Hematite and magnetite mostly form complex aggregates with diameters ranging from 0.001 to 0.02 mm.

3. Results and discussions

3.1 Separation Test of Raw Ore Coarse Grain Sample

Particle size sieving analysis and distribution rate analysis were carried out for crushing products of different sizes of raw ore, the fracture characteristics and particle size distribution of the samples can be obtained. The sieve size of the coarse ore ranges from 0 mm to 10 mm, the positive cumulative and negative cumulative analysis results of particle size sieving of coarse crushing products of raw ores [21, 22] are shown in Table 4.

From the analysis results in the table, it can be seen that the iron grade of -0.074 mm of the coarse sieve analysis results are low in the negative cumulative neutral and positive cumulative analysis, and the grades of the other different sizes of raw ore were of little difference, and the iron grade of -0.074 was only 12.25%. It was indicated that the fine mud with low grade was easy to be produced when crushing or grinding, which will have certain effect on the iron separation process.

3.2 Raw Ore Grinding Particle Size Test

Prepare suitable granular materials for magnetic separation and subsequent sorting operations, the ore was tested for grinding grain size at different times [23]. Two different types of mills were used for the test and the results of the grinding grain size test of different mills at different times of the ore are shown in Figs.5 and 6.

In order to clearly and intuitively understand the particle size of different grinding time, it was convenient to analyze and observe the grain size characteristics of the grinding. The grinding grain size curve of the original ore at different times (XMQ-Φ150×50 cone ball mill) is shown in Fig.5; the grinding grain size curve of time (XMQ-Φ240×90 cone ball mill) is shown in Fig.6.

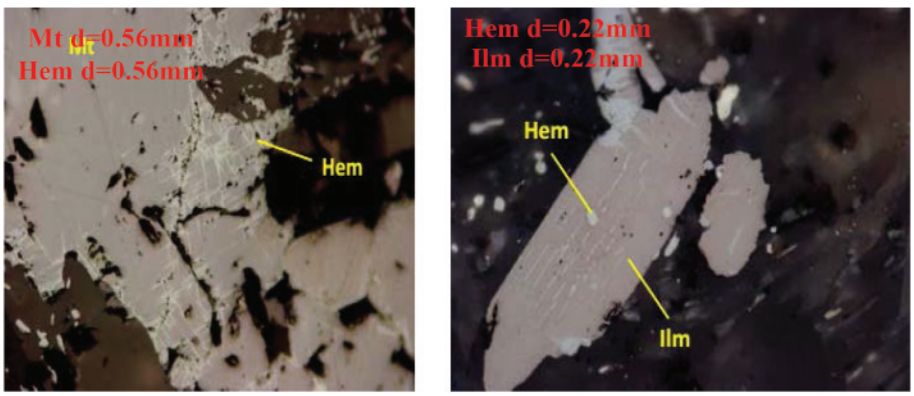

Fig.4 Hematite of different particle sizes

Table 3 The main mineral composition and content of ore (%)

Mineral	Magnetite	Ilmenite Brookite	Hemlimonite	Sericite	Potash feldspar Plagioclase	Zoisite Allanite	Quartz	Sulfide	Others
Content	16.5	2.3	1.1	67.2	4.3	2.5	2.1	1	3

Table 4 Positive cumulative and negative cumulative analysis results of particle size sieving of coarse crushing products of raw ores

Grain size (mm)	Iron grade(TFe) (%)			Distribution rate (%)		
	Single	Positive accumulation	Negative accumulation	Single	Positive accumulation	Negative accumulation
+6.0	17.67	17.67	16.75	48.65	48.65	100
-4.0+2.0	16.44	17.25	15.66	8.62	75.04	33.58
-2+1.0	16.37	17.18	15.41	5.97	81.01	24.96
-1.0+0.074	18.79	17.35	15.14	10.4	91.41	18.99
-0.074	12.25	16.75	12.25	8.59	100	8.59

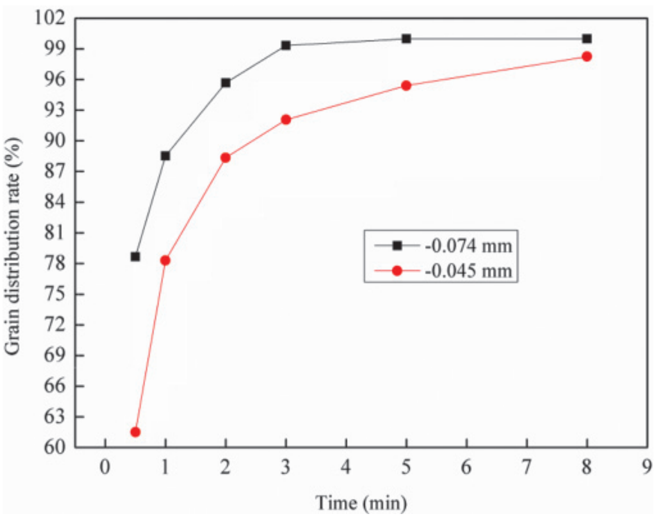

Fig.5 The grinding size curve of raw ore at different time (XMQ-Φ150×50 cone ball mill)

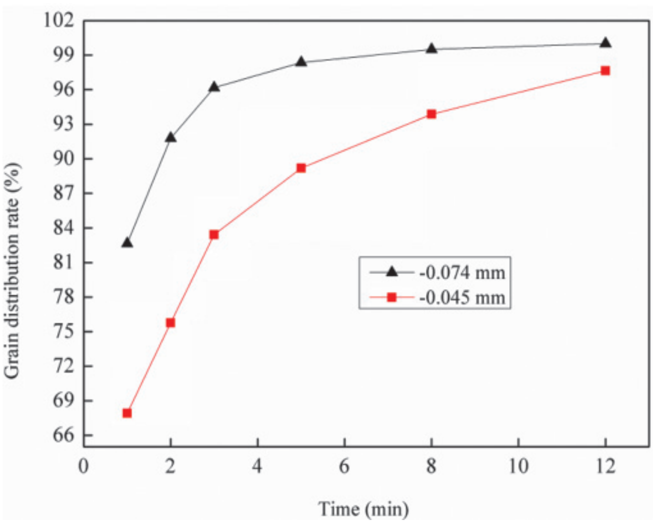

Fig.6 The grinding size curve of raw ore at different time (XMQ-Φ240×90 cone ball mill)

In the above two pictures, when using the XMQ-F150×50 cone ball mill, the ore with a grain size of -0.074 mm was completed in 5 minutes, the ore with a particle size of -0.045 mm achieved a grinding rate of 98.25% at 8 minutes; when using the XMQ-F240×90 cone ball mill, the ore with a grade of -0.074 mm was completed in 12 minutes, while the ore with a grade of -0.045 mm has a grinding rate of 97.66% in 12 minutes. The ore of different grain grades [24] has a shorter grinding time under different types of mills, indicating that the ore was not difficult to grind and a medium-grinding ore, which was very important for improving the grinding rate of the mill.

3.3 Magnetic Analysis Test of Raw Ore Samples

For magnetite, the magnetic analysis of the sample can be used to understand the magnetic separation characteristics of the ore sample, which has important guiding significance and practical significance for guiding magnetic separation production. The magnetic analysis tube [25] was used for magnetic analysis test. The original ore was 60 g, the grinding was carried out for 12 min, sample size of -0.045 mm accounted for 98.25% [16], the magnetic analysis test results of the ore magnetic separator [26] are shown in Figs.7 and 8.

The magnetic analysis results of the magnetic separation tube show that the iron ore (TFe) of the magnetic concentrate product can be reduced from 68.84% to 68.47% by magnetic analysis of the magnetic ore, and the iron recovery rate was increased from 71.16% to 72.87%, the recovery rate has increased; from the obtained tailings [27], the iron grade dropped from 5.73% to 5.36%, and the iron recovery rate dropped from 28.84% to 27.13%. According to the test result data, the magnetic field strength and current of the test were constantly changed, the iron grade and iron recovery rate of the magnetic concentrate product [28] can be gradually increased, thereby obtaining a higher quality iron concentrate product, and it was not difficult to find that the ore has better selectivity. It has great potential to develop, which was very important for us to select the mine.

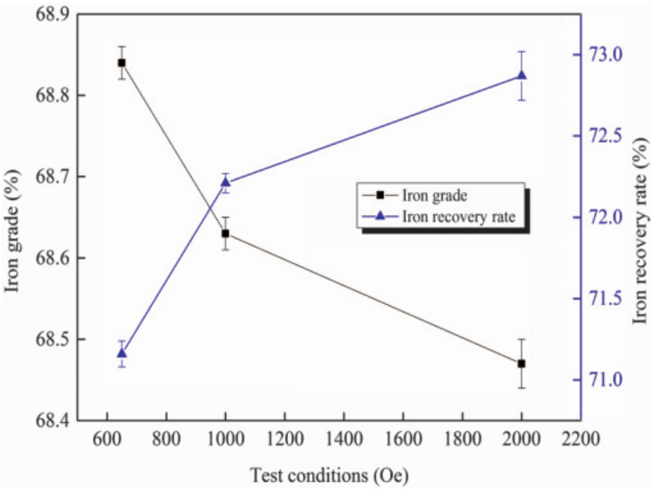

Fig.7 Analysis results of magnetic experiment of weak magnetic concentrates

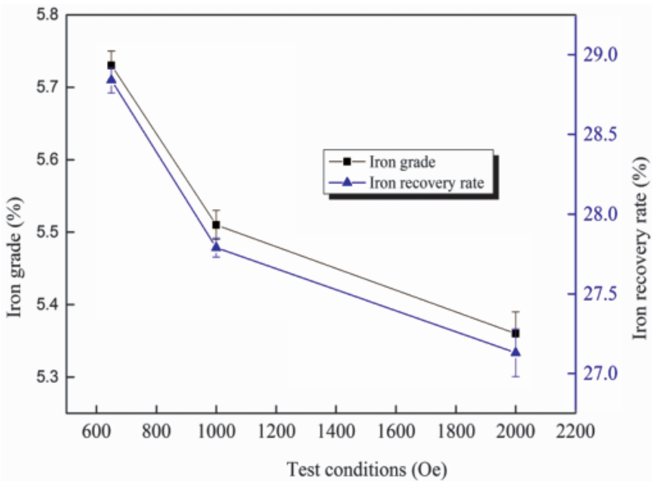

Fig.8. Analysis result of magnetic experiment of weak magnetic separation tailings

3.4 Magnetic Separation Tube Stage Selection Exploration Test

Considering that the mine was a lean magnetite, in order to reduce the cost of grinding and improve the economic benefits of industrial production, the experiment has examined the effect of coarse grain selection. The original ore samples with particle sizes of -1.0 mm and -2.0 mm were directly magnetically selected by magnetic separation tube. The magnetic field strength of the test was 1000 Oe, and the magnetic separation tube stage of different size samples of the original ore sample was explored. The test results are shown in the Table 5.

From the selection of the magnetic separation tube stage selected from the raw ore coarse particles, it was known that the test results were obtained. The coarse particles with a particle size of -2.0 mm were directly magnetically selected by a magnetic separation tube. The magnetic field strength of the separation was 1000 Oe, a coarse concentrate product with an iron grade of 31.27% and an iron recovery of 70.24% will be obtained. Direct magnetic separation of coarse particles with -1.0 mm particle size are carried out by magnetic separation tubes. The magnetic field strength of the sorting was 1000 Oe, the iron grade was 37.8%, and the iron recovery rate was 55.37%. The iron grade increased by 6.53% and the iron recovery rate dropped by 14.87%. It indicates that coarse grinding and rough selection, that is to say, stage grinding will be fruitful and we can discard approximately two-thirds of the rough-selected tailings.

The iron recovery rate of the coarse-grained selection [29] was relatively large, mainly because the selected particle size was relatively coarse, and the selection of the magnetic field conditions of the sorting was not reasonable. Subsequent adjustment of the selected magnetic field strength and selection of appropriate operating conditions will further improve the or iron recovery rate of the coarse concentrate to achieve an ideal sorting effect [30].

3.5 Coarse Grain Dry Tailing Exploration Test

In general, the crushing and grinding costs of the concentrator account for 60% of the total production cost. For the grinding-weak magnetic separation process of the sorting magnetite, the cost of crushing and grinding was higher. Considering that the mine was a lean magnetite, in order to reduce the cost of crushing and grinding, and to explore the sorting effect of coarse-grained dry tailing, it was proposed to use dry magnetic separation directly for samples with particle sizes of -4.0 mm and -6.0 mm. The machine performs magnetic separation and coarse tailing to investigate the sorting effect of the coarse dry tail. The magnetic field strength of the sorting was approximately 6000 Oe, and the results of the coarse-grain dry tailing test of the original ore sample were shown in the Table 6.

From the results of the raw ore coarse-grained dry magnetic separation tailing test in the table. When the raw ore with a particle size of -4.0 mm was used for dry bulk magnetic separator to carry out coarse particle discarding test. The iron grade in the dry tailings was 9.23%, and the

Table 5 Selected results of magnetic separation tube selection for raw ore coarse particles

Test conditions	Product name	Iron grade (%)	Iron recovery rate (%)
-2.0 mm1000 Oe	Weak magnetic separation concentrate	31.27	70.24
	Weak magnetic separation tailings	7.73	29.74
-1.0 mm1000 Oe	Weak magnetic separation concentrate	37.8	55.37
	Weak magnetic separation tailings	9.67	44.63

Table 6 Test results of dry magnetic separation of coarse particles in raw ore

Test conditions(Dry magnetic separation)	Product name	Iron grade (%)	Iron recovery rate (%)
-4.0 mm6000 Oe±	Dry concentrate	18.53	86.78
	Dry tailings	9.23	13.22
-6.0 mm6000 Oe±	Dry concentrate	17.98	90.07
	Dry tailings	8.81	9.93

iron recovery was 13.22%. The iron grade (TFe) of the dry magnetic separation concentrate obtained at this time was 18.53%, and the iron recovery rate was 86.78%. When the raw ore with a particle size of -6.0 mm was used for dry bulk magnetic separator to carry out coarse particle discarding test, the iron grade in the dry tailings was 8.81%, and the iron recovery was 9.93%. The iron grade (TFe) of the dry magnetic separation concentrate obtained at this time was 17.98% and the iron recovery rate was 90.07%. It indicates that the iron grade can be initially increased from 1.68% to 2.18% by dry magnetic separation. However, if the selected particle size was coarser and preselected, the tailing effect was not obvious, which may be related to the finer grain size of the magnetite in the ore.

For lean magnetite, coarse dry pre-selection was beneficial to reduce grinding cost and improving the grade of grinding, which was very beneficial for the subsequent wet separation operation, it was beneficial to improve the overall economic efficiency of the entire concentrator. However, it was necessary to combine the mining costs before the dry pre-selection to comprehensively determine the tailing rate. For the ore, the magnetite was mainly composed of fine grain inlays. From the effect of coarse-grained pre-selected beneficiation, it was recommended to use coarse-grain dry pre-selection in industrial production. It was more appropriate to throw dry tailings with a tailings yield of about 25%.

4. Conclusions

The content of total iron (TFe) in the ore sample was 16.34%, the content of magnetic iron (MFe) was 12.11%, the content of phosphorus (P) was 0.085% and the content of sulfur (S) was 0.048%, it belongs to acid-poor magnetite ore. Through magnetic analysis experiment, the magnetic concentrate product with iron grade of 68.47% and iron recovery of 72.87% can be obtained. Because the distribution rate of ferric silicate in the original ore was 19.89%, it cannot be recovered, this will become an important reason for the low total recovery of iron.

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