



Mechanism of microwave assisted suspension magnetization roasting of oolitic hematite ore

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Abstract: Oolitic hematite is an iron ore resource with rich reserves, complex composition, low grade, fine disseminated particle sizes, and a unique oolitic structure. In this study, a microwave-assisted suspension magnetization roasting technology was proposed to recover and utilize the ore. The results showed that under the conditions of microwave pretreatment temperature of 1050 °C for 2 min, a magnetic concentrate with an iron grade of 58.72% at a recovery of 89.32% was obtained by microwave suspension magnetization roasting and magnetic separation. Moreover, compared with the no microwave pretreatment case, the iron grade and recovery increased by 3.17% and 1.58%, respectively. Microwave pretreatment increased the saturation magnetization of the roasted products from 24.974 to 39.236 (A · m²)/kg and the saturation susceptibility from 0.179 × 10⁻³ m³/kg to 0.283 × 10⁻³ m³/kg. Microcracks were formed between the iron and gangue minerals, and they gradually extended to the core of oolite with the increase in the pretreatment time. The reducing gas diffused from outside to inside along the microcracks, which promoted the selective transformation of the weak magnetic hematite into the strong magnetic magnetite.

Key words: oolitic hematite; microwave; suspension magnetization roasting; phase and magnetic transformation; microstructure evolution

Cite this article as: ZHOU Wen-tao, SUN Yong-sheng, HAN Yue-xin, GAO Peng, LI Yan-jun. Mechanism of microwave assisted suspension magnetization roasting of oolitic hematite ore [J]. Journal of Central South University, 2022, 29(2): 420–432. DOI: <https://doi.org/10.1007/s11771-022-4937-5>.

1 Introduction

Oolitic hematite is recognized as the most difficult type of iron ore worldwide owing to its fine grain size, easy sliming, and difficult separation of

harmful elements [1–3]. Scientific researchers have conducted extensive studies on the utilization of oolitic hematite ore, which could be specifically divided into the physical beneficiation process, leaching process, reduction (magnetization roasting and direct reduction), magnetic separation process,

Foundation item: Projects(51874071, 51734005, 52104257) supported by the National Natural Science Foundation of China; Project(161045) supported by the Fok Ying Tung Education Foundation for Yong Teachers in the Higher Education Institutions of China

Received date: 2021-04-29; **Accepted date:** 2021-08-09

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and smelting process [4, 5]. The grade of the iron concentrate obtained by the single flotation, selective flocculation reverse flotation, combined flotation, and magnetic separation process is approximately 56%, and the iron recovery is 50%–70% [4]. Therefore, it is difficult to achieve efficient utilization of the oolitic hematite ore by conventional beneficiation methods. Microbial and acid leaching processes can effectively reduce impurities. However, microbial leaching requires comparatively a more stringent operation process and a longer leaching cycle. Concurrently, the acid leaching process causes significant corrosion to equipment, has a high cost, and majorly contributes to pollution. Therefore, the current leaching process has not been industrialized in the field of iron ore. Using direct reduction followed by a magnetic separation process to treat oolitic hematite ore could achieve an improved separation effect. However, owing to the low iron grade of oolitic hematite ore and the complex process, the problems of high energy consumption and high cost in the process of application become highly prominent. From long-term practice, it has been proved that magnetization roasting followed by magnetic separation technology is one of the most effective methods for enriching iron minerals from refractory iron ores [6, 7]. In recent years, fluidization magnetization roasting technology with high heat and mass transfer efficiency and microwave roasting technology with green, clean, and selective rapid heating advantages are important development directions in the field of magnetization roasting of refractory iron ore [8]. In view of the problems existing in the traditional magnetization roasting technology, HAN et al [9] proposed a new concept of iron ore called “pre-oxidation – heat storage reduction – reoxidation” for suspension magnetization roasting. Moreover, they successfully developed the laboratory and pilot equipment for conducting iron ore suspension magnetization roasting.

Microwave heating has the advantages of selective and rapid heating. It has broad application prospects in the field of high-energy consumption mining and metallurgy. Among its potential applications, microwave pretreatment technology and microwave magnetization roasting magnetic separation technology are commonly studied for complex refractory iron ores. QIAN et al [10]

studied the influence of microwave pretreatment on the grindability and microstructure of oolitic hematite ore from western Hubei, China. The results showed that increasing the microwave power and prolonging the treatment time could promote the ore liberation and improve the grinding capacity. Moreover, the specific surface area and porosity of the ore sample were significantly improved, and cracks and cross-sections were formed in the ore after the microwave pretreatment. OMRAN et al [11] compared the grinding effects of microwave and conventional pretreatments on the oolitic hematite ore in Egypt and found that microwave pretreatment could significantly reduce the grinding energy consumption compared to conventional pretreatment. SHI et al [12] conducted microwave magnetization roasting and dry magnetic separation to treat siderite from Shaanxi Province, China. The results showed that an iron concentrate with an iron grade of 40.21% and an iron recovery of 89.53% could be obtained under the condition of microwave magnetization temperature of 650 °C for 25 min. Concurrently, it was found that the iron phase changed from siderite to magnetite and magneto-hematite, and the magnetite presented a monomer or loose sponge shape, which was beneficial for the subsequent grinding and separation. Summarizing, microwave pretreatment technology can destroy the internal structure of oolitic hematite but strengthen the grinding effect. Compared with conventional electric furnace magnetization technology, microwave magnetization roasting technology significantly shortens the reaction time, saves energy, and reduces consumption and has significant economic and environmental advantages.

Based on the characteristics of microwave roasting technology, we consider using microwaves, a clean and green energy, for the suspension magnetization roasting of refractory iron ores. Therefore, by meeting the requirement of rapid and selective heating of materials, it can not only enhance the heat and mass transfer efficiency of materials but also reduce the combustion pollution of petrochemical energy. In this study, to explore the influence mechanism of microwave pretreatment on the suspension magnetization roasting in a microwave heating system, its regulation mechanism was explored by conducting single-factor experiments. The influence mechanism of the

microwave pretreatment on the phase, magnetism, and microstructure evolution of the suspension magnetization roasting products was explored via X-ray diffraction (XRD), vibrating sample magnetometer (VSM) measurements, and scanning electron microscopy-energy dispersive spectrometry (SEM-EDS).

2 Materials and methods

2.1 Materials

Raw materials were collected at distinct points in the Tunqiu iron mine in Liuzhou, China, and were used as test samples after crushing, screening, mixing, and shrinking. The results of the chemical multi-element analysis are summarized in Table 1 [13, 14]. Table 1 shows that the TFe grade of the ore is 46.70%. The main impurities are SiO_2 and Al_2O_3 with contents of 19.17% and 5.71%, respectively; the harmful element is P with a content of 1.00%.

Table 1 Chemical composition of oolitic iron ore (wt%)

TFe	FeO	P	SiO_2	Al_2O_3	CaO	MgO	K_2O	Na_2O	LOI
46.70	2.43	1.00	19.17	5.71	2.45	0.30	0.63	0.18	4.25

To ascertain the presence of iron in the ore, the phase of the iron element was analyzed, and the results are summarized in Table 2 [13, 14]. Table 2 shows that the main phase of the iron element in the ore is hematite with a content of 39.20% and a distribution rate of 84.07%. It is followed by limonite with a content of 4.56% and a distribution rate of 9.78%, and the other iron phases are in smaller contents.

Table 2 Chemical phase analyses of iron in ore

Mineral	Content/wt%	Distribution rate/%
Hematite	39.20	84.07
Limonite	4.56	9.78
Siderite	0.72	1.54
Magnetite	0.09	0.19
Pyrite	0.17	0.36
Silicate	1.89	4.06

To clarify the composition and contents of the minerals in the ore sample, they were analyzed by electron microscopy and energy spectrum analysis. The results are summarized in Table 3 [13, 14].

Table 3 Statistical results of mineral composition and content in ore

Mineral	Content/%
Hematite	60.02
Limonite	8.55
Siderite	1.69
Pyrite	0.37
Magnetite	0.12
Other sulfide minerals	<0.01
Phosphate minerals	8.35
Quartz	12.41
Kaolinite	5.07
Chlorite	1.12
Mica	1.28
Carbonate minerals	0.43
Feldspar, amphibole and pyroxene	0.34

2.2 Methods and equipment

The main equipment used in the test was a self-designed and manufactured microwave suspension roasting furnace. The equipment is shown in Figure 1.

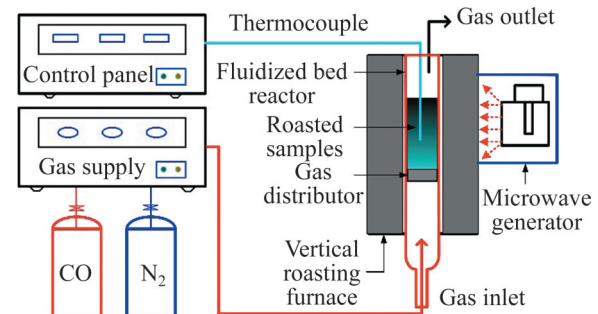


Figure 1 Schematic diagram of microwave suspension roasting system

This study mainly focused on the microwave suspension magnetization roasting (M-SMR) process and the microwave pretreatment followed by microwave suspension magnetization roasting (M-PSMR) process. The operation method of the M-SMR process was as follows: an appropriate amount of the raw ore sample was placed in a roasting tube, and an appropriate amount of N_2 was introduced to empty the air in the tube. When the roasting temperature reached a predetermined value, an appropriate amount of CO was started to be introduced. When the predetermined roasting time was reached, CO was stopped immediately, but N_2 was continued to be introduced. The roasting tube

was removed and cooled to room temperature in N₂ atmosphere. The operation method of the M-PSMR process was as follows: an appropriate amount of the raw ore sample was placed in the microwave roasting tube, and 250 mL/min N₂ was introduced. The microwave heating power was 1300 W, and the microwave constant-temperature power was 500 – 600 W. The microwaves were stopped immediately when the pretreatment time reached, and the material in the roasting tube was poured into the basin to prepare a microwave pretreatment sample. The operation method of the microwave magnetization roasting test of a pretreatment sample was consistent with that of the M-SMR process.

The raw materials and products were analyzed via XRD (pw3040, Netherlands) to study their main mineral compositions and phase transformation processes [15, 16]. A VSM (daw-2000d, China) was used to analyze the magnetic properties of the test products [17]. The working parameters were as follows: working temperature of 298 K, vibrating frequency of 180 Hz, and sample mass of 50 mg. SEM-EDS (Tescan Mira3, Czech Republic) was conducted to characterize the microstructures and compositions of the samples [18, 19].

3 Results and discussion

3.1 Thermodynamic analysis

The reaction equilibrium module of HSC 6.0 Chemistry software was used to calculate the thermodynamics of the chemical reactions that may occur in the M-PSMR process of the ore. The main theoretical basis of the reaction equilibrium module is the principle of the minimum Gibbs free energy and the principle of entropy increase. The main iron minerals of oolitic hematite ore were hematite, limonite, and siderite, and the gangue minerals were quartz, apatite, and kaolinite. For convenient calculation, the chemical compositions of the above substances were simplified as Fe₂O₃, Fe₂O₃·H₂O, FeCO₃, SiO₂, Ca₅(PO₄)₃OH, and Al₂O₃·2SiO₂·2H₂O using the HSC Chemistry software, respectively. The calculation conditions were as follows: the maximum temperature of the pretreatment process 1373 K in N₂ atmosphere and maximum temperature of the suspension magnetization roasting process was 1000 K in a CO and N₂ mixed

Table 4 Thermodynamic equations of M-PSMR process

Thermodynamic reaction	No.
2Ca ₅ (PO ₄) ₃ OH(s)=3Ca ₃ (PO ₄) ₂ (s)+CaO(s)+H ₂ O(g)	1
2Ca ₅ (PO ₄) ₃ OH(s)+SiO ₂ (s)=3Ca ₃ (PO ₄) ₂ (s)+CaO·SiO ₂ (s)+H ₂ O(g)	2
2Ca ₅ (PO ₄) ₃ OH(s)+Al ₂ O ₃ ·2SiO ₂ ·2H ₂ O(s)=3Ca ₃ (PO ₄) ₂ (s)+CaO·Al ₂ O ₃ ·2SiO ₂ (s)+3H ₂ O(g)	3
Al ₂ O ₃ ·2SiO ₂ ·2H ₂ O(s)=Al ₂ O ₃ ·2SiO ₂ (s)+2H ₂ O(g)	4
Fe ₂ O ₃ (s)+FeCO ₃ (s)=Fe ₃ O ₄ (s)+CO ₂ (g)	5
Fe ₂ O ₃ ·H ₂ O(s)=Fe ₂ O ₃ (s)+H ₂ O(g)	6
Fe ₃ O ₄ (s)+4CO(g)=3Fe(s)+4CO ₂ (g)	7
FeO(s)+CO(g)=Fe(s)+CO ₂ (g)	8
Fe ₃ O ₄ (s)+CO(s)=3FeO(s)+CO ₂ (g)	9
3Fe ₂ O ₃ (s)+CO(g)=2Fe ₃ O ₄ (s)+CO ₂ (g)	10
FeO(s)+SiO ₂ (s)=FeO·SiO ₂ (s)	11
2FeO(s)+SiO ₂ (s)=2FeO·SiO ₂ (s)	12
FeO(s)+Al ₂ O ₃ (s)=FeO·Al ₂ O ₃ (s)	13
2FeO(s)+2Al ₂ O ₃ (s)+5SiO ₂ (s)=Fe ₂ Al ₄ Si ₅ O ₁₈ (s)	14
3FeO(s)+Al ₂ O ₃ (s)+3SiO ₂ (s)=Fe ₃ Al ₂ Si ₃ O ₁₂ (s)	15
CaO(s)+Fe ₂ O ₃ (s)=CaO·Fe ₂ O ₃ (s)	16
2CaO(s)+Fe ₂ O ₃ (s)=2CaO·Fe ₂ O ₃ (s)	17
CaO(s)+2SiO ₂ (s)+FeO(s)=CaFe(SiO ₃) ₂	18

atmosphere. The calculation results are shown in Table 4 and Figure 2.

In the range of the microwave pretreatment temperature, the limonite, siderite, kaolinite, and apatite in the ore underwent thermal decomposition or a dehydroxylation reaction. Siderite reacted with hematite in N₂ atmosphere to form Fe₃O₄ and CO₂; kaolinite was transformed into metakaolin after dehydroxylation reaction. Under the action of kaolinite or quartz, hydroxyapatite could spontaneously undergo a dehydroxylation reaction, and kaolinite or quartz could reduce the dehydroxylation temperature of hydroxyapatite to a certain extent. In the range of the microwave suspension magnetization roasting temperature, when the roasting temperature was higher than 843 K, iron oxides were reduced in the order of Fe₂O₃→Fe₃O₄→FeO→Fe. Compared to other reduction processes of iron oxides, the reaction of hematite to magnetite was extremely easy to occur, and the trace CO could also reduce Fe₂O₃ to Fe₃O₄. FeO formed in the over reduction process could react with SiO₂, Al₂O₃, or CaO chemical components to form iron complex compounds, such as ferroolivine (2FeO·SiO₂), iron spinels (FeO·Al₂O₃),

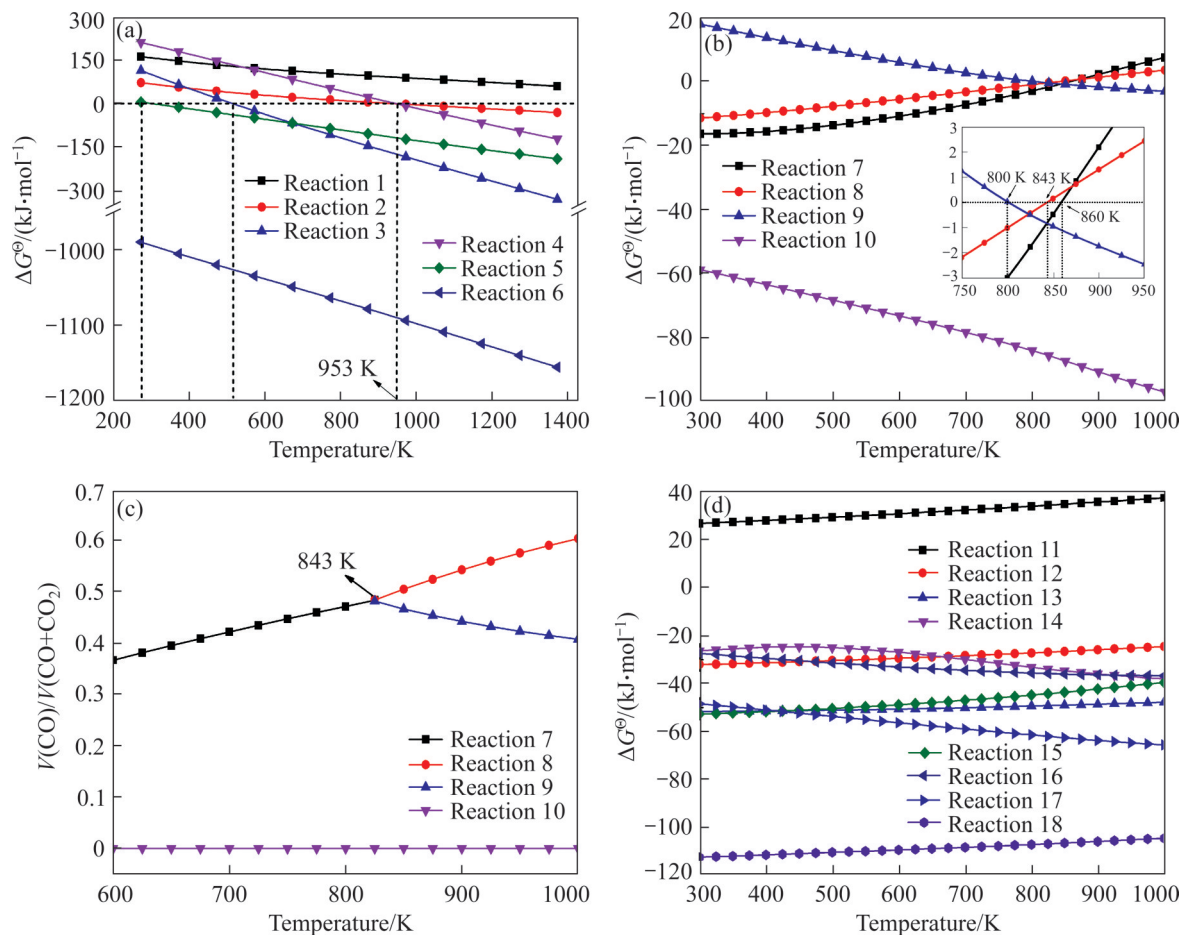


Figure 2 Reaction thermodynamics of oolitic hematite ore in M-PSMR process: (a) Gibbs free energy of reactions 1–6 varying with roasting temperature; (b) Gibbs free energy of reactions 7–10 varying with roasting temperature; (c) Equilibrium phase components of iron oxides reduced by CO; (d) Gibbs free energy of reactions 11–18 varying with roasting temperature

or calcium iron pyroxene ($\text{CaFe}(\text{SiO}_3)_2$). Therefore, in the magnetization roasting test, the roasting conditions should be strictly controlled to avoid formation of these iron complex compounds.

3.2 Effect of microwave pretreatment on suspension magnetization roasting

The roasting temperature, roasting time, CO content, and total gas volume have important effects on magnetization roasting. To explore the effect of microwave pretreatment on magnetization roasting, the effects of the roasting temperature, roasting time, CO content, and total gas volume on magnetization roasting before and after pretreatment (microwave pretreatment temperature 1050 °C, pretreatment time 2 min) were discussed. The results are shown in Figure 3.

Figure 3 indicates that with the increase of roasting temperature, roasting time, CO content, and

total gas volume, the iron grade of the magnetic concentrate changes slightly. In comparison, the iron recovery initially increases and subsequently decreases; this is because appropriately increasing in the roasting temperature, CO content, and total gas volume is conducive for promoting the transformation of a weak magnetic mineral to a strong magnetic mineral. The effective separation of the iron and gangue minerals could be realized by magnetic separation. However, with a continuous increase of roasting temperature, roasting time, CO content, and total gas volume, the ferrous oxide produced by the over reduction reaction could react with gangue minerals to form iron complex minerals [20]. Some examples are as augite, forsterite, and spinel, and their generation further weakened the effect of magnetization roasting [21].

Therefore, the optimal conditions of suspension magnetization roasting under microwave

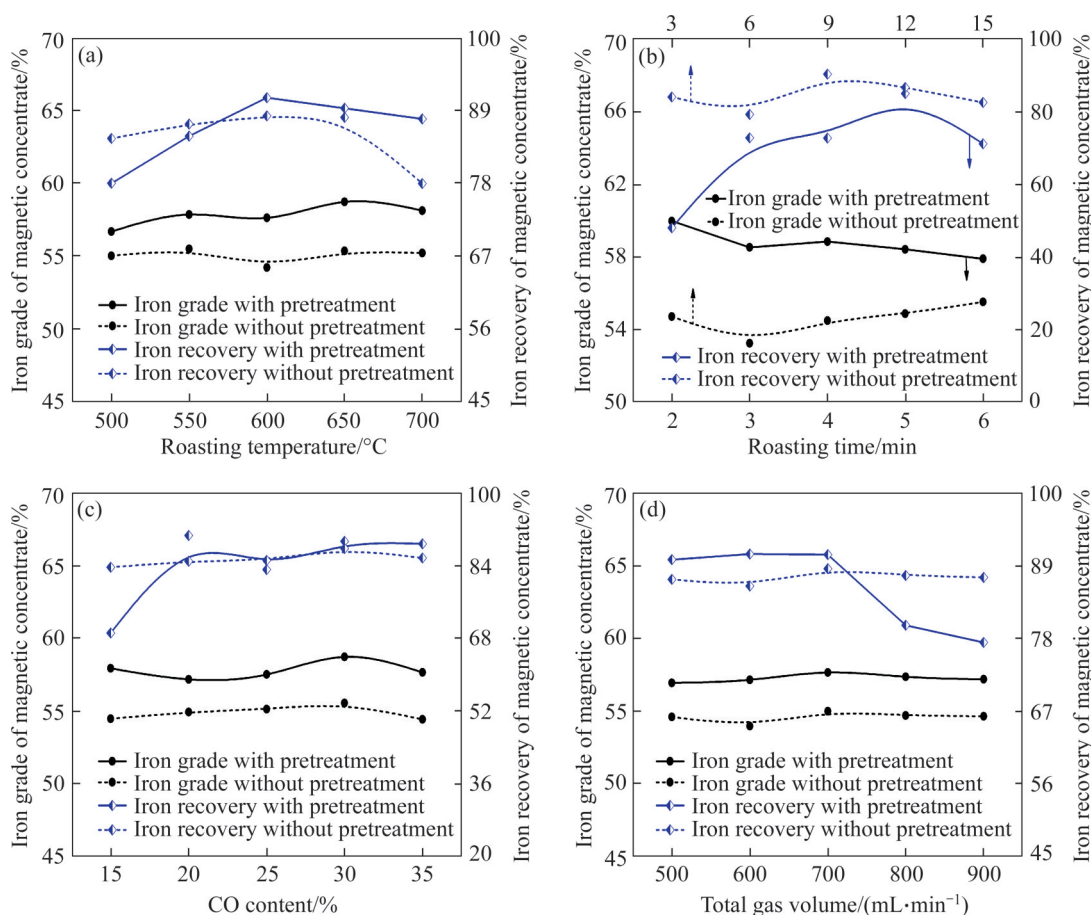


Figure 3 Effects of different factors before and after microwave pretreatment on suspension magnetization roasting: (a) Roasting temperature; (b) Roasting time; (c) CO content; (d) Total gas volume

pretreatment were obtained as follows: roasting temperature of 650 °C, roasting time of 5 min, CO content of 30%, and total gas volume of 700 mL/min. The iron grade and recovery of the magnetic concentrate were 58.72% and 89.32%, respectively, under these optimal conditions. Concurrently, the optimal conditions of suspension magnetization roasting without microwave pretreatment were as follows: roasting temperature of 650 °C, roasting time of 9 min, CO content of 30%, and total gas volume of 700 mL/min. Under these optimal conditions, the iron grade and recovery of the magnetic concentrate were 55.55% and 87.74%, respectively. Therefore, compared to the magnetic concentrate obtained by the M-SMR process, the M-PSMR process had significantly improved iron grade and iron recovery, which were increased by 3.17 and 1.58 points, respectively.

3.3 Phase analysis of products

To explore the phase compositions of the

roasted and concentrate products under the M-PSMR (the optimized conditions are as follows: roasting temperature of 650 °C, roasting time of 5 min, CO content of 30%, and total gas volume of 700 mL/min) and M-SMR processes (the optimized conditions are as follows: roasting temperature of 650 °C, roasting time of 9 min, CO content of 30%, and total gas volume of 700 mL/min), XRD analysis was conducted, and the results are shown in Figure 4.

Figure 4 shows that a magnetite [311] crystal plane characteristic diffraction peak appears at 35.46° for both roasted and concentrate products under both processes, indicating that some hematite is transformed into magnetite. The diffraction peaks of hematite and apatite still persist in the roasted product of the M-SMR process; however, they are absent in the roasted product of the M-PSMR process. This indicates that compared with the M-SMR process, the M-PSMR process could enhance the transformation of hematite to

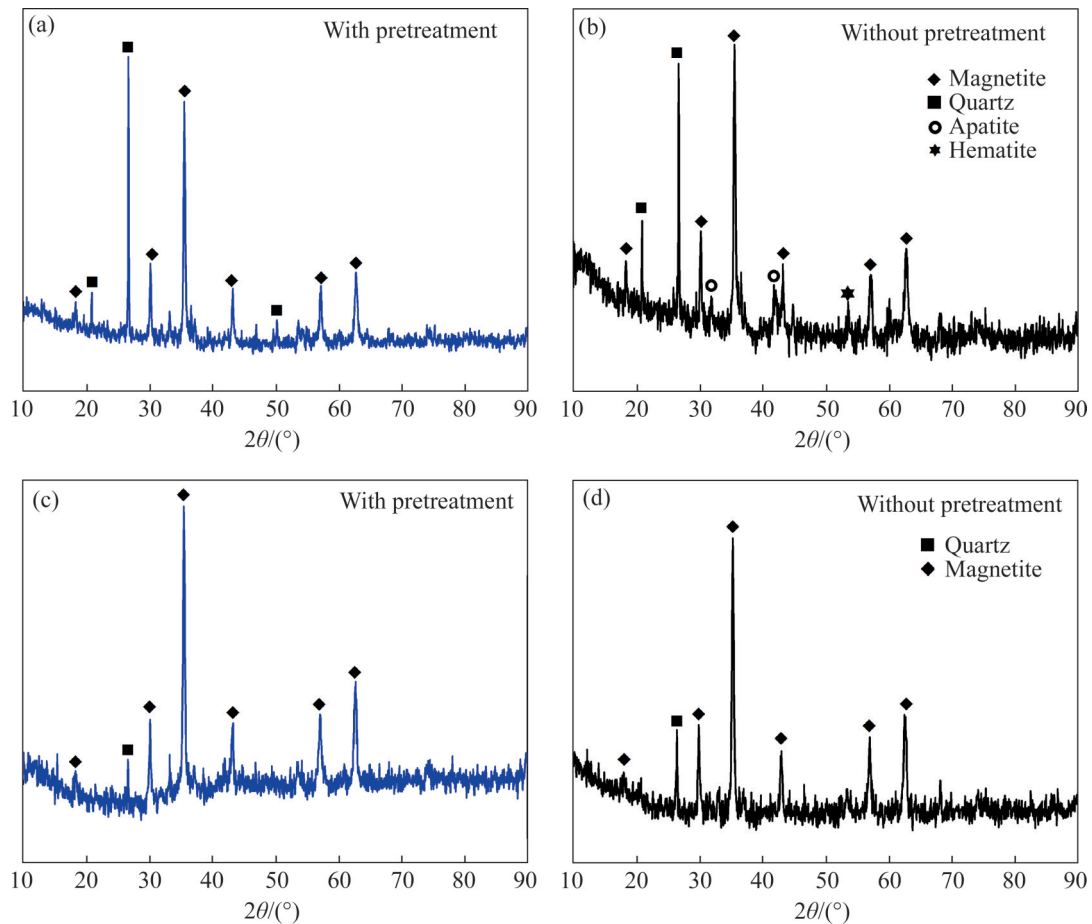


Figure 4 XRD analysis of roasting product (a, b) and magnetic separation concentrate product (c, d) in M-PSMR and M-SMR processes

magnetite, and the hydroxyapatite contained in the ore could undergo dehydroxylation after microwave pretreatment.

3.4 Magnetic analysis of products

A VSM was used to analyze the magnetic properties of the M-PSMR and M-SMR roasting and concentrate products, as shown in Figure 5.

Figures 5(a) and (b) show that with the increase in the external magnetic field strength, the magnetization of the roasted product initially increases rapidly and subsequently gradually flattens. Similarly, the magnetic susceptibility first increases rapidly and subsequently gradually decreases. When the external magnetic field intensities were 500 and 59 kA/m, respectively, the magnetization and susceptibility of the roasting products by the M-SMR and M-PSMR processes tended to be saturated. The corresponding saturation magnetizations were 24.974 and 39.236 ($A \cdot m^2$)/kg and the corresponding saturation susceptibilities

were $0.179 \times 10^{-3} \text{ m}^3/\text{kg}$ and $0.283 \times 10^{-3} \text{ m}^3/\text{kg}$, respectively. Compared to the saturation magnetizations and susceptibilities of the roasting products of the M-SMR process, those of the roasting products of the M-PSMR process were significantly improved. This indicated that microwave pretreatment could promote the transformation of a weak magnetic iron ore to a strong magnetic iron ore and enhance the effect of magnetization roasting.

3.5 Effect of microwave pretreatment on product microstructure evolution

To explore the influence of microwave pretreatment on the surface microstructure of roasted products, SEM analysis was conducted on the roasted products obtained before and after microwave pretreatment, and the results are shown in Figure 6.

Figures 6(a1, a2) show that the ore surface is smooth and dense. After M-SMR, the surface of

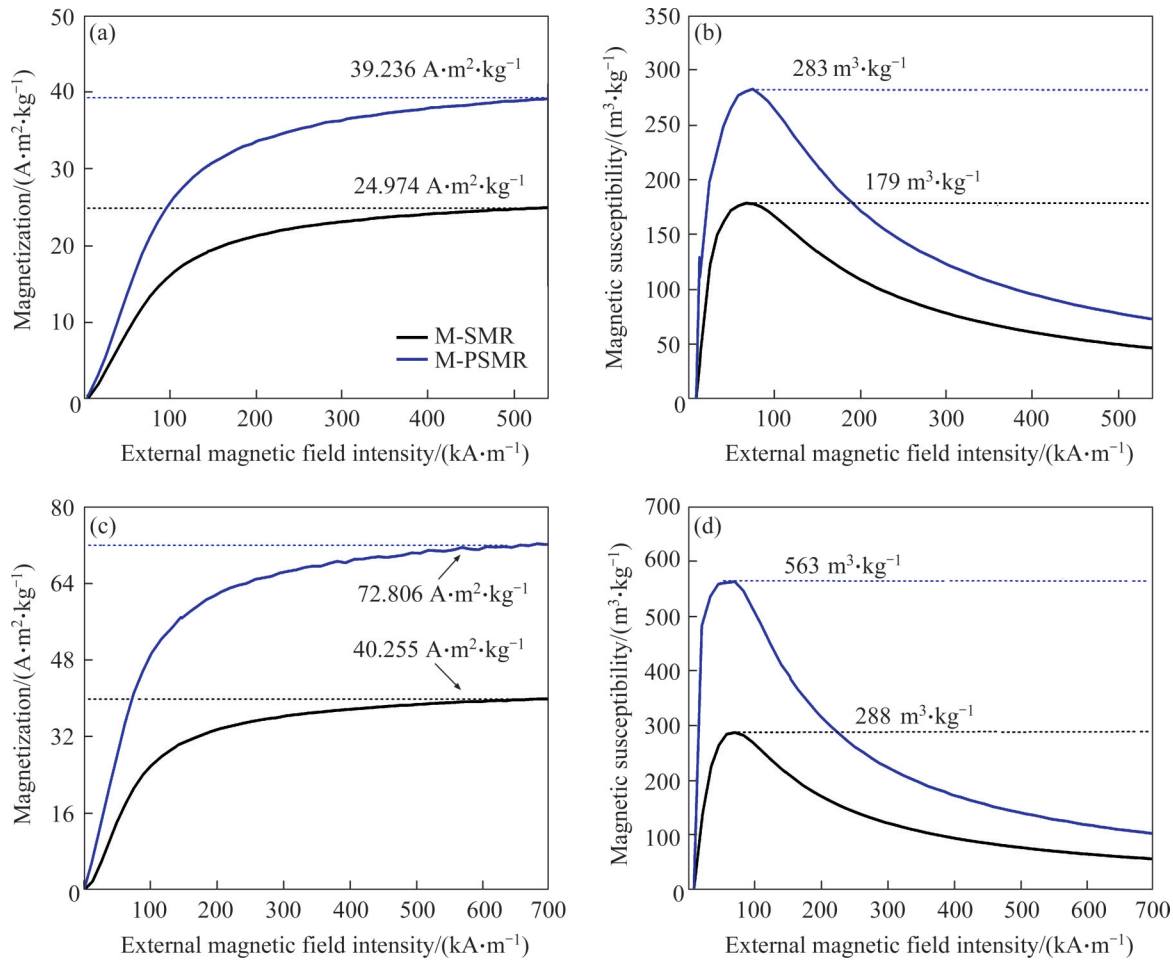


Figure 5 Magnetic analysis of M-PSMR and M-SMR roasting products: (a) Magnetization; (b) Susceptibility; and concentrate products: (c) Magnetization; (d) Susceptibility

roasted product particles becomes loose and rough (Figures 6(b1, b2)). After M-PSMR, the surface structure of roasted product particles is further damaged, showing honeycomb morphology, which indicated that M-PSMR had greater damage to the microstructure of ore (Figures 6(c1, c2)).

To explore the evolution law of internal microstructure of microwave pretreatment products during magnetization roasting, SEM-EDS was used to observe and analyze the internal microstructure of raw ore and different roasting products with particle size from 0.15 to 0.425 mm. The results are shown in Figures 7 and 8, respectively.

Figure 7 exhibits that the ore presents a typical concentric ring structure. EDS spectrum indicates that point 1 is mainly composed of Al, Si, O and Fe, which are kaolinite, chlorite or mixed minerals with quartz; point 2 is mainly composed of Fe and O, which is hematite; point 3 and point 5 are mainly composed of Si and O, which is quartz; point 4 is

mainly composed of Fe and O, which is hematite. The results show that hematite and gangue minerals such as quartz and kaolinite condense layer by layer to form concentric layered oolitic structure. Figure 8 presents that microcracks between the mineral interfaces of the pretreatment products increase significantly with an increase of roasting time, and the color of iron minerals changes from dark gray to bright gray near microcracks. Figures 8(a) and (b) show that there are microcracks at the boundary of minerals. According to EDS spectrum, the constituent elements of point 1 and point 3 are Si and O, indicating that these areas are mainly composed of quartz; the constituent elements of point 2 and point 4 are Fe and O, indicating that these areas are mainly composed of iron minerals. Figure 8(c) shows that there are microcracks in both the outer edge and the inner core of the oolite, and the microcracks extending to the inner of the oolite

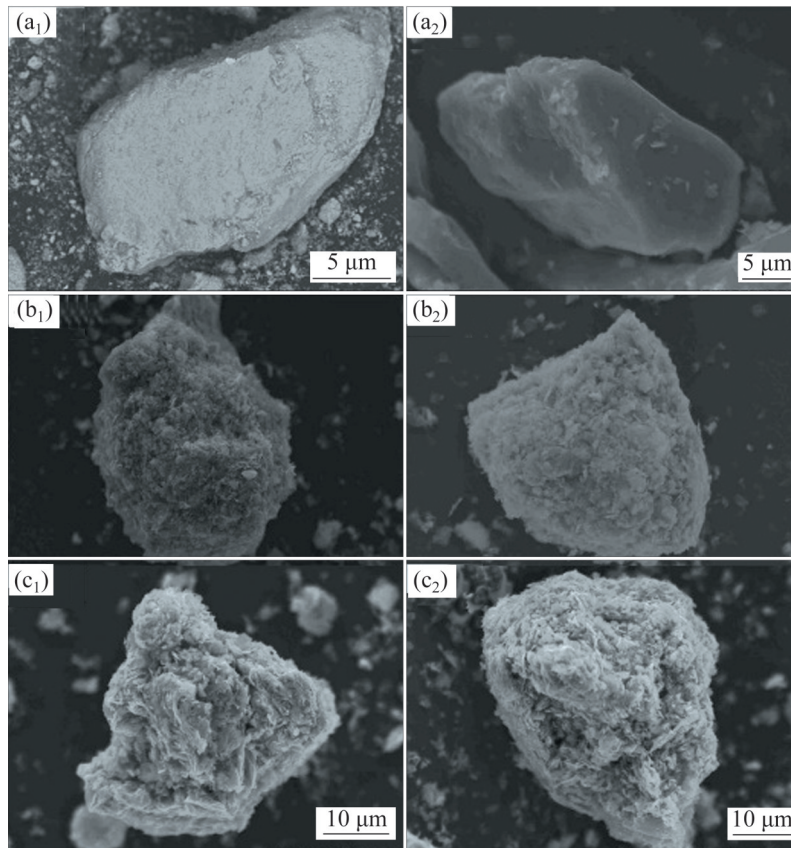


Figure 6 Comparison of ore microstructure: (a₁, a₂) Raw ore; (b₁, b₂) M-SMR roasted products; (c₁, c₂) M-PSMR roasted products

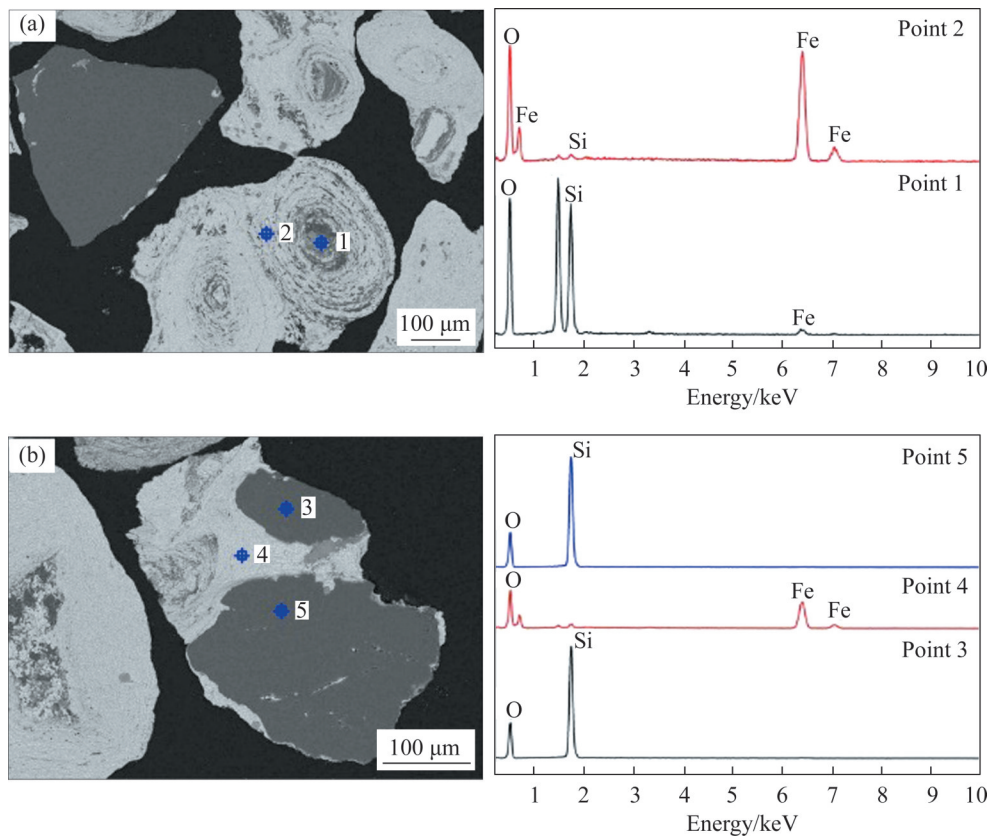


Figure 7 SEM images and EDS spectra of raw ore

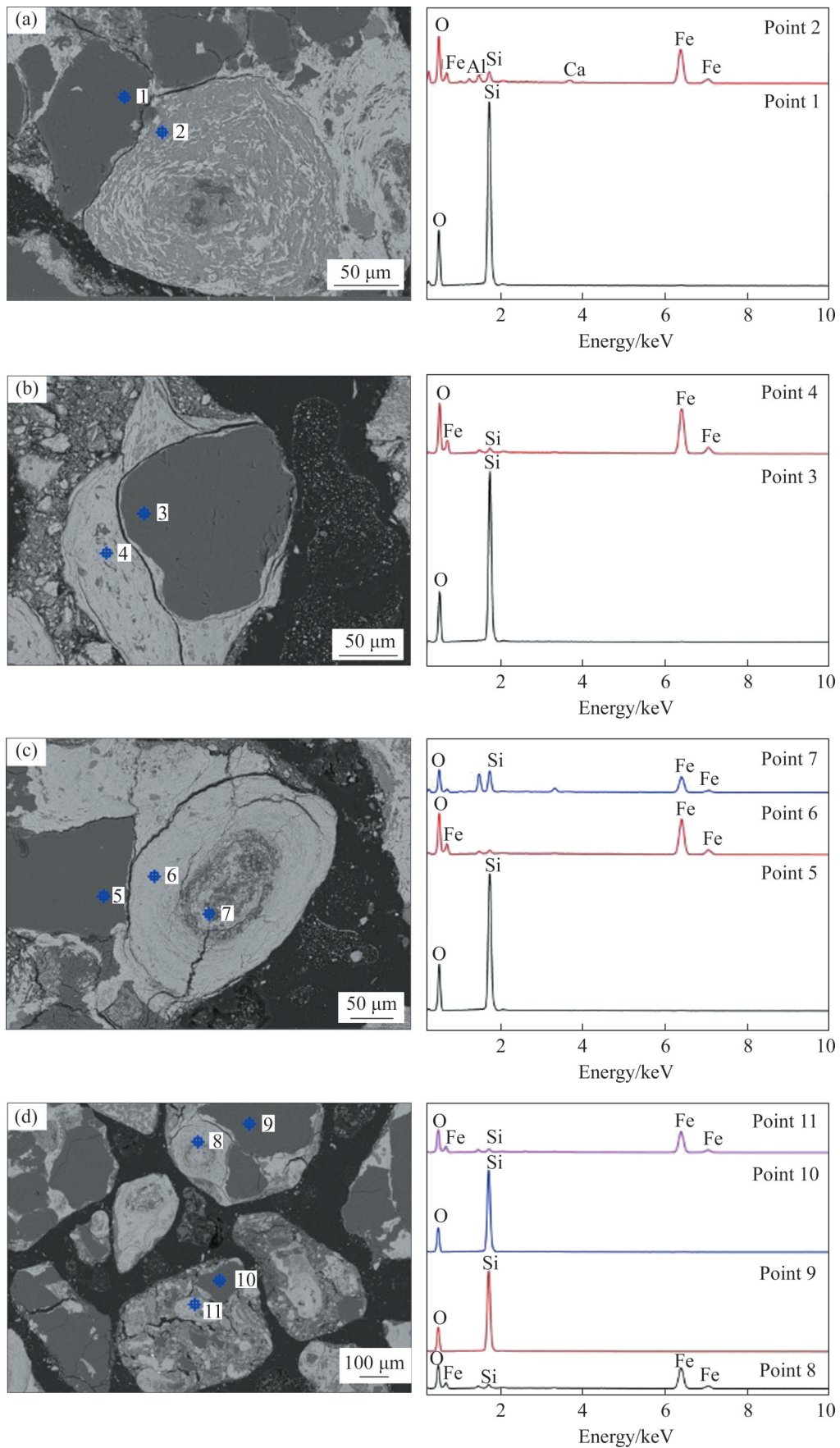


Figure 8 SEM images and EDS spectra of products at different magnetization roasting time: (a) 0.5 min; (b) 1.0 min; (c) 3.0 min; (d) 5.0 min

are connected with the microcracks in the inner core of the oolite. Figure 8(d) manifests that there are obvious microcracks at the boundary between dark gray area and light gray area in the ore. According to the theoretical calculation, the mass ratio of iron atom to oxygen atom of hematite (Fe_2O_3), magnetite (Fe_3O_4) and ferrous oxide (FeO) was 2.33, 2.65 and 3.50, respectively. Because the mineral contained other oxides, according to the calculation of Fe/O in EDS under different magnetization roasting conditions, the value range of the mass ratio of iron atom to oxygen atom of hematite is $0 < w(\text{Fe})/w(\text{O}) < 2.33$; the value range of the mass ratio of iron atom to oxygen atom of magnetite is $2.33 < w(\text{Fe})/w(\text{O}) < 2.65$; the value range of the mass ratio of iron atom to oxygen atom of ferrous oxide is $2.65 < w(\text{Fe})/w(\text{O}) < 3.50$. The value of $w(\text{Fe})/w(\text{O})$ can be used to characterize the reduction degree of iron oxide near microcracks. According to the calculation in Figure 8, the $w(\text{Fe})/w(\text{O})$ values of iron oxide near the microcrack under different magnetization roasting time are obtained, as shown in Figure 9.

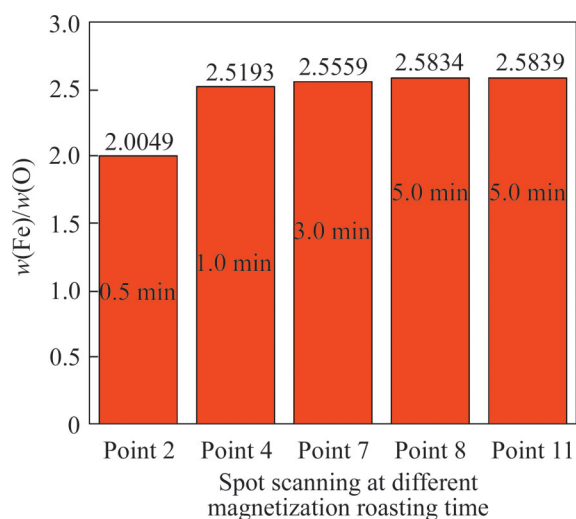


Figure 9 $w(\text{Fe})/w(\text{O})$ values of iron oxides near microcracks under different magnetization roasting time

Figure 9 indicates that with an increase in magnetization roasting time, the $w(\text{Fe})/w(\text{O})$ value of iron oxide near the microcrack gradually increases from 2.005 at 0.5 min to 2.5839 at 5 min, which showed that the phase of iron ore near the microcrack had been transformed from hematite to magnetite. In the process of magnetization roasting, CO gas molecules enter into the oolite along the microcracks and loose pores. The iron minerals near

microcracks and loose pores in the oolite provide more contact areas for the roasting reaction. With an increase of roasting time, the contact areas involved in the reaction are increased, and the transformation rate from hematite to magnetite is accelerated.

4 Conclusions

In view of the current situation where it was difficult to develop and utilize oolitic hematite ore in China, based on a technical concept of “microwave heating combined with suspension magnetization roasting to treat refractory iron ore”, a small-scale experimental equipment for microwave suspension roasting was designed and manufactured for the first time, and a new M-PSMR technology was creatively proposed and adopted to treat the ore. The optimum conditions of M-PSMR process were as follows: microwave pretreatment temperature of 1050 °C for 2 min, magnetization roasting temperature of 650 °C for 5 min, CO concentration of 30%, and total gas volume of 700 mL/min. Under the optimized conditions, an iron concentrate with an iron grade of 58.72% at a recovery of 89.32% was obtained. Compared with M-SMR process, the iron grade and recovery of this process were increased by 3.17% and 1.58% respectively, and the roasting time was shortened. M-PSMR process could make the roasted products easier to produce microcracks and more loose structure, increase the magnetization and susceptibility of roasted products, moreover strengthen the transformation from hematite to magnetite.

Contributors

ZHOU Wen-tao provided the concept and edited the draft of manuscript. SUN Yong-sheng conducted the data curation and formal analysis. HAN Yue-xin, GAO Peng and LI Yan-jun conducted the supervision and edited the draft of manuscript. All authors replied to reviewers' comments and revised the final version.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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(Edited by ZHENG Yu-tong)

中文导读

鲕状赤铁矿微波辅助悬浮磁化焙烧机理研究

摘要: 鲕状赤铁矿是一种储量丰富、成分复杂、品位低、粒度细、鲕状构造独特的铁矿资源。本文提出了微波辅助悬浮磁化焙烧回收利用该矿石的工艺。结果表明,在微波预处理温度 1050 °C、时间 2 min 的条件下,微波预处理的效果较好;预处理产品采用微波悬浮磁化焙烧-磁选工艺,获得铁品位 58.72%,回收率 89.32% 的磁精矿。与无微波预处理相比,铁品位和回收率分别提高了 3.17% 和 1.58%。微波预处理使磁化焙烧产品的饱和磁化强度由 24.974 (A·m³)/kg 提高到 39.236 (A·m³)/kg,饱和磁化率由 0.179×10⁻³ m³/kg 提高至 0.283×10⁻³ m³/kg。随着预处理时间的延长,铁矿物与脉石矿物之间形成微裂纹,并逐渐扩展到鲕粒核心。还原气体沿微裂纹由外向内扩散,促进了弱磁性赤铁矿向强磁性磁铁矿选择性转化。

关键词: 鲕状赤铁矿; 微波; 悬浮磁化焙烧; 相变和磁相变; 微观结构演化