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Recrystallization of Fe₂O₃ During the Induration of Iron Ore Oxidation Pellets

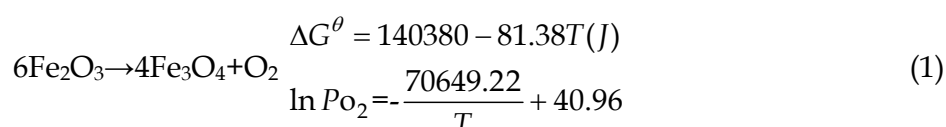
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1. Introduction

Magnetite and hematite concentrates are the two main raw materials for oxidized pellet production. Magnetite concentrates have more predominance due to the heat release by oxidation during roasting and may reduce energy consumption (Jiang et al., 2008; Li et al., 2009). However, with the continuous consumption of iron resources driven by the rapid development of iron and steel industry, magnetite resources are becoming scarce and so the development of pellet production is restricted to some extent. Thus, it is imperative to make better use of hematite resources to meet the raw material supply for pellet production (Xu, 2001).

In the pelletizing process, the firing of hematite materials leads to the development of pellet strength by oxide crystal bridging, recrystallization of the Fe₂O₃, as well as the formation of a small quantity of slag (Ball et al., 1973).

As for the firing of hematite materials, more heat should be supplied from external sources due to the absence of the exothermic reaction of oxidation of magnetite. So the energy consumption of hematite pellet production is greater than that of magnetite pellets (Jiang et al., 2008). Moreover, it has been shown that hematite pellet has poor roasting properties and do not achieve adequate physical strength until the roasting temperature is higher than 1300°C. Findings show that the hematite particles and pellet structure keep their original shapes if the temperature is below 1200°C. Thus, the size of hematite particles are not enlarged, nor the Fe₂O₃ crystal lattice defects are eliminated until the temperature is higher than 1300°C. At high temperatures, initial connecting bridges are formed between crystal grains and recrystallization of Fe₂O₃ is observed. However, if the roasting temperature is too high (>1350°C), something detrimental would happen as Fe₂O₃ decomposes to Fe₃O₄ expressed as reaction (1), which adversely results in the loss of pellet quality :



From the thermodynamic equation of reaction (1), it can be seen that decomposition temperature of Fe₂O₃ increases with increasing oxygen partial pressure. Therefore,

excessively high firing temperature and low oxygen partial pressure should be avoided to restrain the decomposition of Fe_2O_3 . Thus, it is necessary to maintain at higher roasting temperature for hematite pellet as well as narrower firing temperature range, which makes the operation of firing equipments difficult.

To enhance the induration of hematite pellets, both magnetite-addition and carbon-burdened methods are found to be the favourable techniques in practice. In this chapter, the induration mechanisms of hematite pellet with addition of magnetite concentrate and anthracite powder are revealed by characterization of recrystallization rules of Fe_2O_3 during the oxidization roasting.

2. Fe_2O_3 recrystallization during the firing of mixed hematite/magnetite concentrates pellet

2.1 Materials and methods

2.1.1 Materials

The chemical compositions of iron ore materials and bentonite are shown in Table 1. The size distribution of iron concentrates is shown in Table 2.

Materials	Fe _{total}	FeO	SiO ₂	CaO	MgO	Al ₂ O ₃
Hematite	67.60	0.72	1.55	0.15	0.17	1.16
Magnetite	69.31	27.88	1.32	0.23	0.55	1.02
Bentonite	4.38	/	59.05	0.68	1.73	18.72

Table 1. Chemical compositions of materials / %

Materials	+0.075mm	0.0375-0.075mm	-0.0375mm
Hematite	13.50	16.35	70.15
Magnetite	5.93	15.35	78.72

Table 2. Size distribution of iron ore materials / %

2.1.2 Methods

The experimental procedure includes ball preparation, preheating and roasting tests, strength measurement and mineralogical analysis.

For each trial, 5 kg mixed concentrates at the given hematite/magnetite (H/M) ratio was blended with 8% moisture and 0.5% bentonite was used as binder. The green balls were prepared in a disc pelletizer with a diameter of 1000 mm. The green balls of 10-12 mm in diameter were statically dried at 105°C in an electrical furnace for 4 hrs.

Preheating and roasting tests were carried out in an electrically heated horizontal tube furnace with an internal and external diameter of 50 mm and 70 mm respectively. Firstly,

the dry balls were put into a corundum crucible and pushed into the preheating zone of the furnace step by step, preheated at the given temperature for a given period. Then the preheated pellets were taken out of the furnace and cooled in the air, or directly pushed forwards into a higher temperature zone for roasting. Finally, the roasted pellets were taken out and naturally cooled in the air.

The compression strength of cooled pellets was measured with an LJ-1000 material experimental machine. An average value of 20 pellets is expressed as the compression strength for each test.

2.2 Effects of H/M ratio on the compression strength of pellet

According to the orthogonal experimental results, the relationship between H/M ratio in pellet and the compression strength of preheated and roasted pellet was investigated and shown in Fig. 1. Experimental conditions are preheating temperature of 900°C and preheating time of 10 min for Fig. 1a, and 900°C preheating temperature, 10 min preheating time, 1275°C roasting temperature and 15 min roasting time for Fig. 1b.

It can be seen from Fig. 1a, that the preheated pellet strength is continuously improved from 190 N/P to 1132 N/P when magnetite ratio is increased from 0 to 100%. The main reason is that magnetite has fine particle size and great specific surface area, and magnetite particles are rapidly oxidized into Fe_2O_3 grains during the preheated stage; moreover, the atoms on the newborn Fe_2O_3 grain surface have greater migrating capability than those on the original hematite grains, and consequently the Fe_2O_3 crystallites are easily formed between particles. It also can be found that the compression strength of roasted pellet increases with magnetite ratio below 70%; above 70%, the strength will be decreased with the addition of magnetite. This may be due to the fact that some of magnetite particles are residual in the core of pellet during the preheating stage, which cannot be completely oxidized in the high temperature roasting stage; the magnetite particles are recrystallized and bonded with the formation of slag phases.

2.3 Firing properties of mixed H/M pellet

2.3.1 Preheating characteristics

2.3.1.1 Compression strength of preheated pellet

The effects of preheating parameters on the compression strength of preheated pellets with different H/M ratios are shown in Fig. 2. It can be seen from Fig. 2a that the strength of pellet with H/M=70:30 reaches 559 N/P when preheated at 900°C for 10 min, while the strength of pellet with H/M=50:50 exceeds 560 N/P when the time is more than 5 min. Fig. 2b shows that the preheated pellet strength keeps increasing with the preheating temperature varying from 800 to 1000°C . The strength of the pellets with H/M=50:50 reaches 470 N/P when the temperature is 800°C . However, the compression strength of the preheated pellets with H/M=70:30 is less than 400 N/P until the temperature is over 850°C . Thus, the results show that the preheating time can be shortened and preheating temperature can be decreased with the increase of magnetite ratio in the pellet.

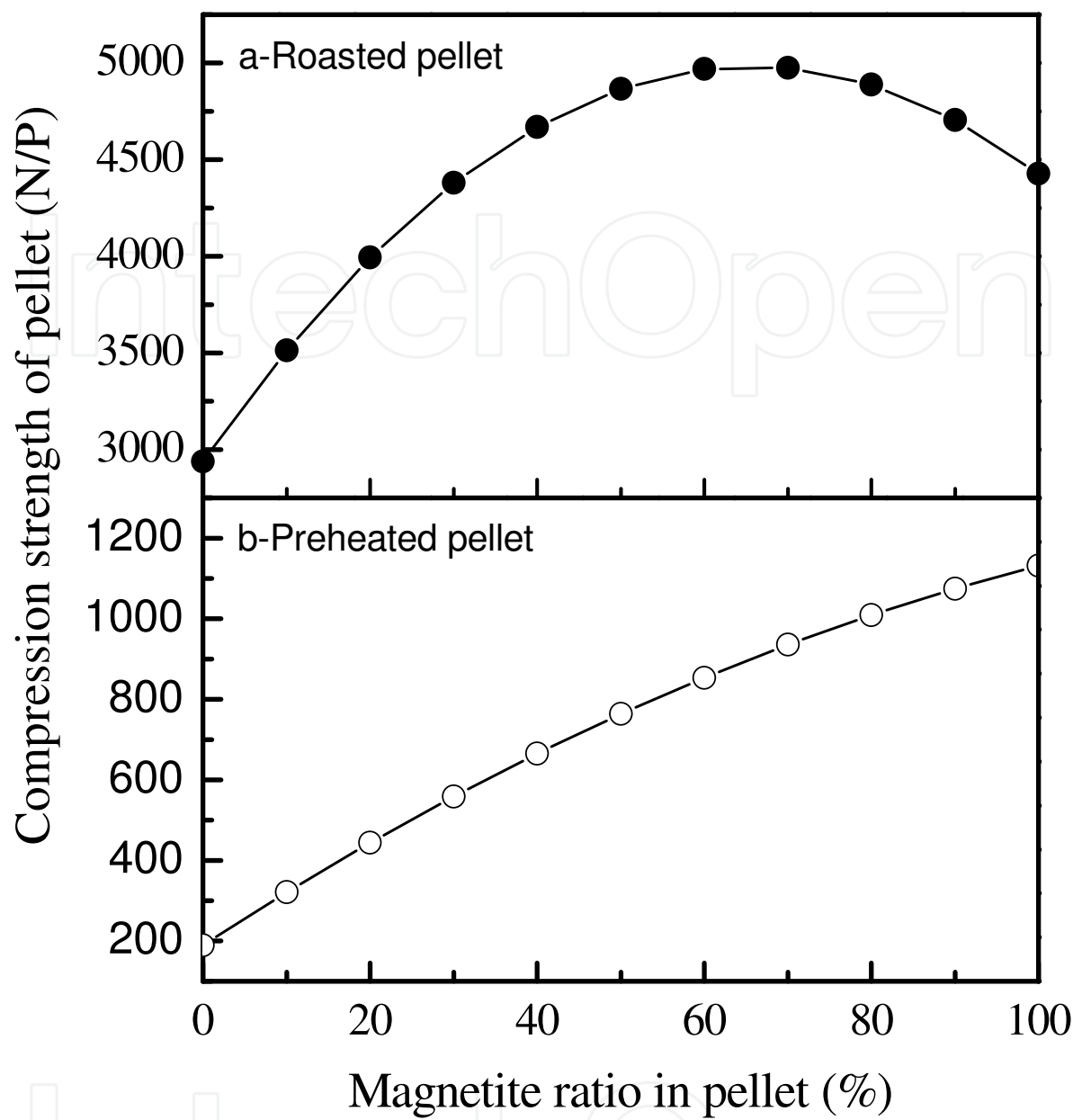


Fig. 1. Effects of magnetite ratio on the compression strength of pellet

2.3.1.2 FeO content of preheated pellet

Whether the magnetite in pellet is oxidized completely or not has an important effect on the roasted pellet performance (compression strength, microstructure, mineral composition, etc.). Generally speaking, residual FeO content in the preheated pellet is required to be less than 3% in operation. The FeO content in pellets with H/M=70:30 under different preheating conditions were analyzed and are shown in Fig. 3. FeO content falls gradually with the increase in preheating temperature and time. FeO content is less than 3% only if the preheating time is more than 11 min at 850°C; however, at 900°C, FeO content goes down to 2.97% when the preheating time is 8 min. In consideration of the compression strength and FeO content together, the suitable preheating parameters for the pellet with H/M=70:30 should be 8~11 min at 850°C~900°C.

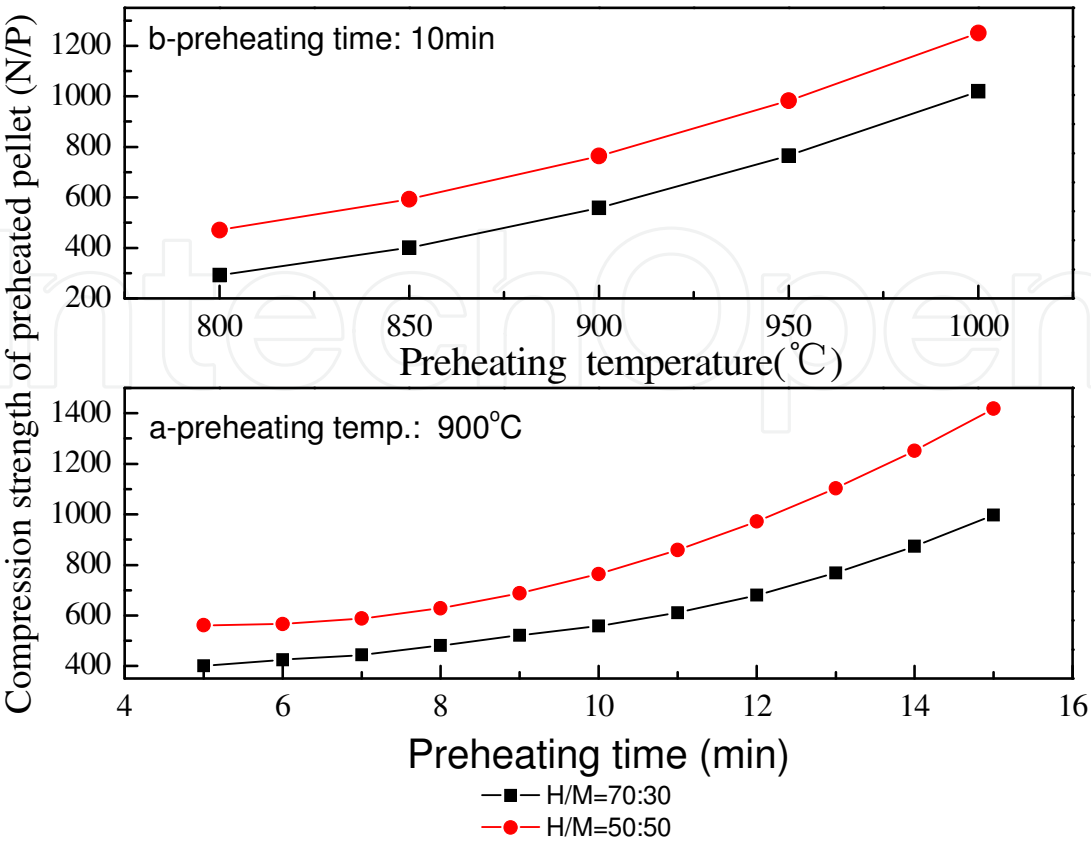


Fig. 2. Effects of preheating on the compression strength of the preheated pellets with different H/M ratios

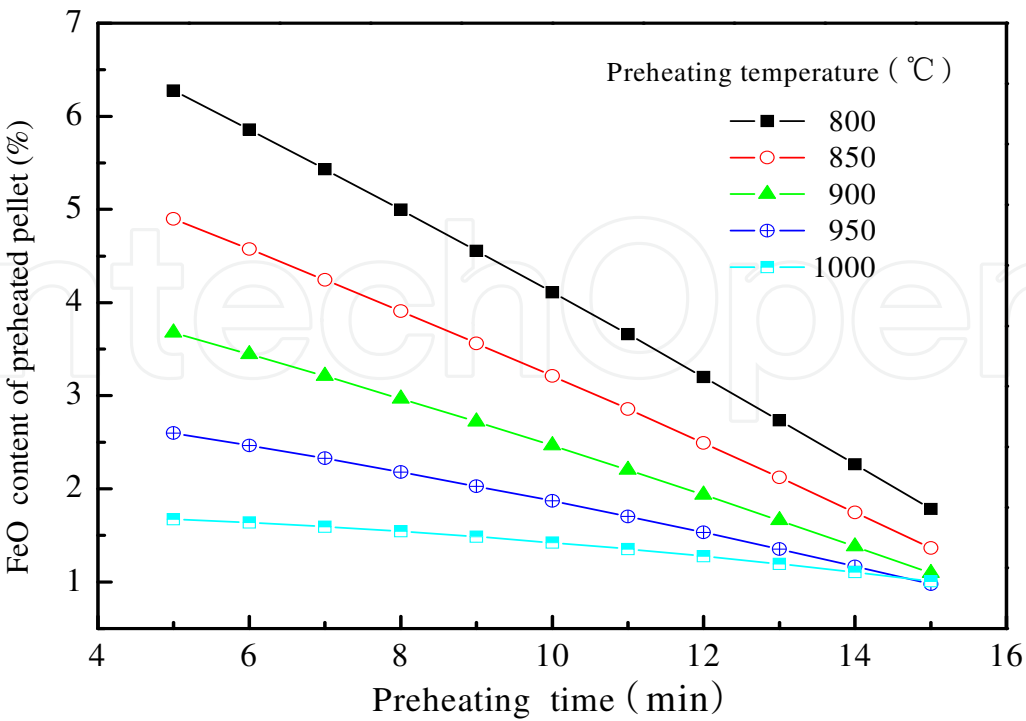
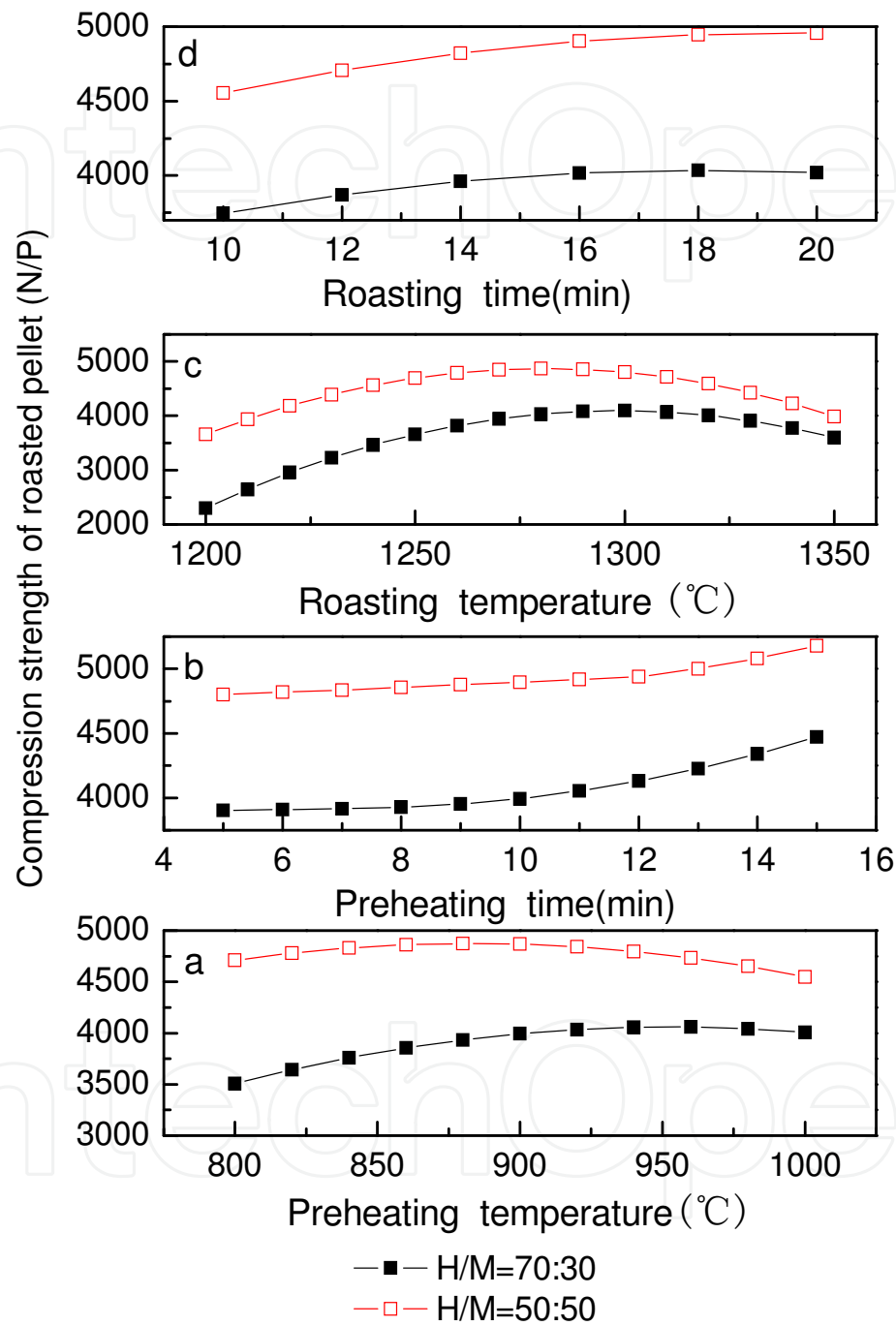


Fig. 3. Effects of preheating on FeO content of the preheated pellets with H/M=70:30

2.3.2 Roasting characteristics

The effects of preheating and roasting parameters on the compression strength of the finished pellets with different H/M ratios are presented in Fig. 4.



a-preheating time 10 min, roasting temp. 1275°C, roasting time 15 min;
b-preheating temp. 900°C, roasting temp. 1275°C, roasting time 15 min;
c-preheating temp. 900°C, preheating time 10 min, roasting time 15 min;
d-preheating temp. 900°C, preheating time 10 min, roasting temp. 1275°C

Fig. 4. Effects of preheating and roasting parameters on the compression strength of the finished pellet with different H/M ratios

As shown in Fig. 4a, the compression strength of roasted pellets increases quickly with the preheating temperatures varying from 800 to 900°C and remains almost unchanged when temperature is between 900 and 950°C. While the temperature is further increased, the pellet strength decreases slightly. The main reason is that a compact layer is quickly formed and the residual magnetite in the core of pellet is difficult to be oxidized completely. If pellet is roasted in poor oxidative atmosphere at relatively high temperature, low melting point slag phases (such as $2\text{FeO} \cdot \text{SiO}_2$) are formed, and result in deteriorating the compression strength of roasted pellet. From Fig. 4b, the strength of the roasted pellets increased gradually with increasing preheating time, the reason for which is that magnetite particles are gradually oxidized into Fe_2O_3 crystallites and they are recrystallized more completely with the prolonged preheating time.

As shown in Fig. 4c, the pellet strength increases steadily with the increase of roasting temperature below 1300°C. The possible reason is that the Fe_3O_4 is gradually oxidized into Fe_2O_3 , which leads to Fe^{3+} diffusion, rearrangement of Fe_2O_3 crystal lattices and a compact microstructure formed. When the roasting temperature is over 1300°C, however, the pellet strength is reduced with rising temperature, the main reason for which is that: on one hand, it is too late for the residual magnetite in the core of preheated pellet to be oxidized adequately at high temperature, so that low melting point slag phases are formed priorly; and on the other hand, part of Fe_2O_3 crystal grains decomposes at high temperature reversely, so that the structure of the pellet is destroyed to some degree. As far as the roasting time is concerned, as given in Fig. 4d, the pellet strength is significantly improved with the roasting time in the range of 10–15 min and remains constant after 15 min.

The results mentioned above show that adding a proper proportion of magnetite concentrate into the hematite pellet is able to improve the compression strength of both preheated and roasted pellets.

2.4 Induration mechanisms of mixed H/M pellet

Mineral composition, microstructure and Fe_2O_3 crystallization of fired pellets at various preheating and roasting temperatures were studied by using Leica DMRXE microscope with an automatic image analyzer.

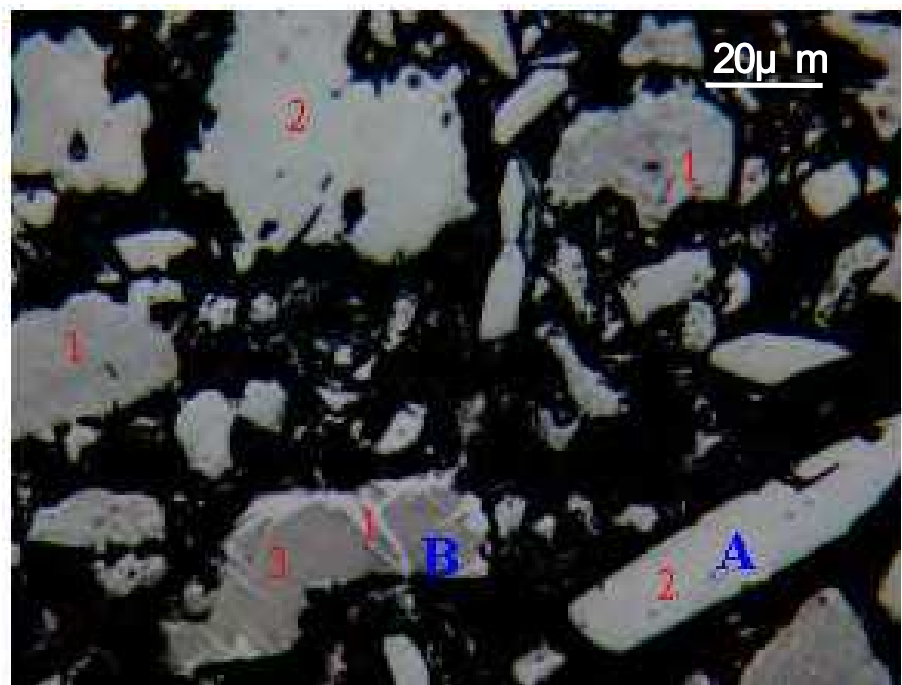
2.4.1 Crystallization behavior of Fe_2O_3 during preheating

Oxidation of magnetite into hematite is the main reaction during preheating. Oxygen readily diffuses into the interior of the porous pellet and reacts with magnetite particles during preheating. Oxidation always occurs firstly on the surface of particles and cracks, and usually a few small spotty or lamellae hematite are formed (Figs. 5, 6). The oxidation process will advance towards the core with increasing temperature.

It is shown that the hematite in the pellets involves two types: the one is original hematite (OH), which is the unreacted hematite from the raw hematite concentrate (particle A), and the other, namely secondary hematite (SH), is formed from the oxidation of magnetite concentrate (particle B).

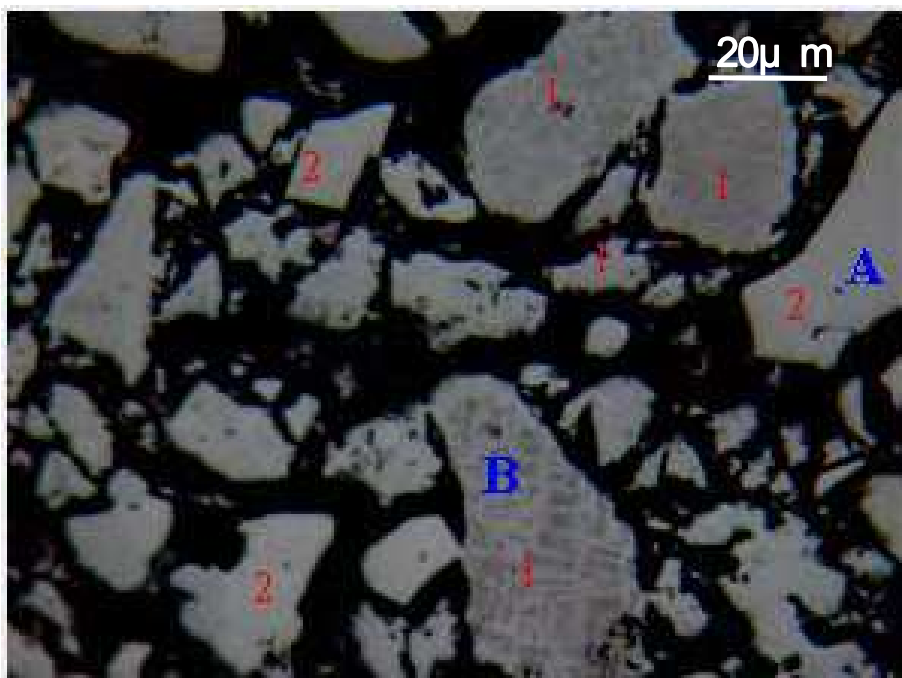
Obvious differences in colour and shape can be observed between the OH and SH grains. For the OH grains, their colours are bright and white, and their shapes are original and with

discernible angularity. The strip, triangular and rectangular grains can be distinctly observed, and the surface of crystal grain is smooth and the compact inner structure is unchanged. Moreover, the distance between the two close OH particles is large; there is no crystallitic bond formation between them.



1-SH (columnar); 2-OH; 3-residual magnetite (irregular, tabular)

Fig. 5. Shapes of SH and OH grains in the pellet preheated at 950°C



1-SH (reticular); 2-OH; 3-residual magnetite (vein)

Fig. 6. Shapes of SH and OH grains in the pellet preheated at 1000°C

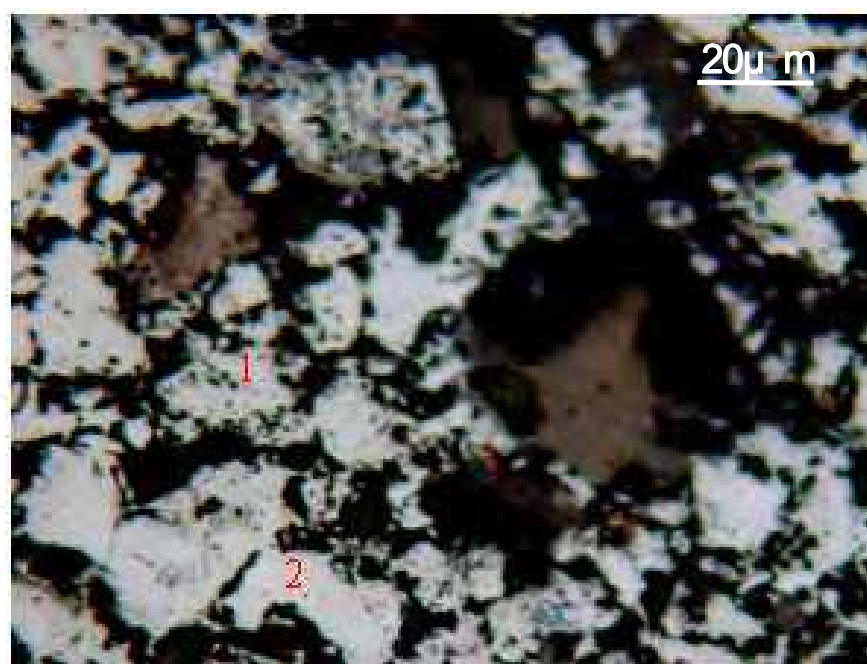
By contrast, for the SH grains, they are relatively heavy-coloured, and some residual magnetite domains can be observed. Tabular or massive grains are the main morphology of residual Fe_3O_4 preheated at 950°C (Fig.5), but the grains change into reticular and vein shape at 1000°C (Fig. 6).

In comparison with OH grains, the angularities of the SH particles disappear or become unclear during oxidation, and they transform into massive, zonal or columnar-shaped particles. The formation of Fe_2O_3 microcrystalline junctions between the close SH particles is significantly different from the OH particles at this stage.

The above results suggest that Fe_2O_3 in SH particles is more active than that in the OH particles. Fe_2O_3 microcrystalline junctions between SH particles are formed when the pellet is preheated, which is able to improve the strength of the preheated pellet. The OH particles keep their original shapes, and no Fe_2O_3 microcrystalline junction can be observed at the preheating stage, thus OH has little contribution to the strength of preheated pellets. Therefore, the improvement of oxidative atmosphere during preheating is able to enhance Fe_2O_3 microcrystalline junctions between the SH particles, the strength of preheated pellet will be improved accordingly.

2.4.2 Crystallization behaviour of Fe_2O_3 during roasting

The crystal morphology of Fe_2O_3 and microstructure of pellets roasted at different temperatures are shown in Figs. 7-9.

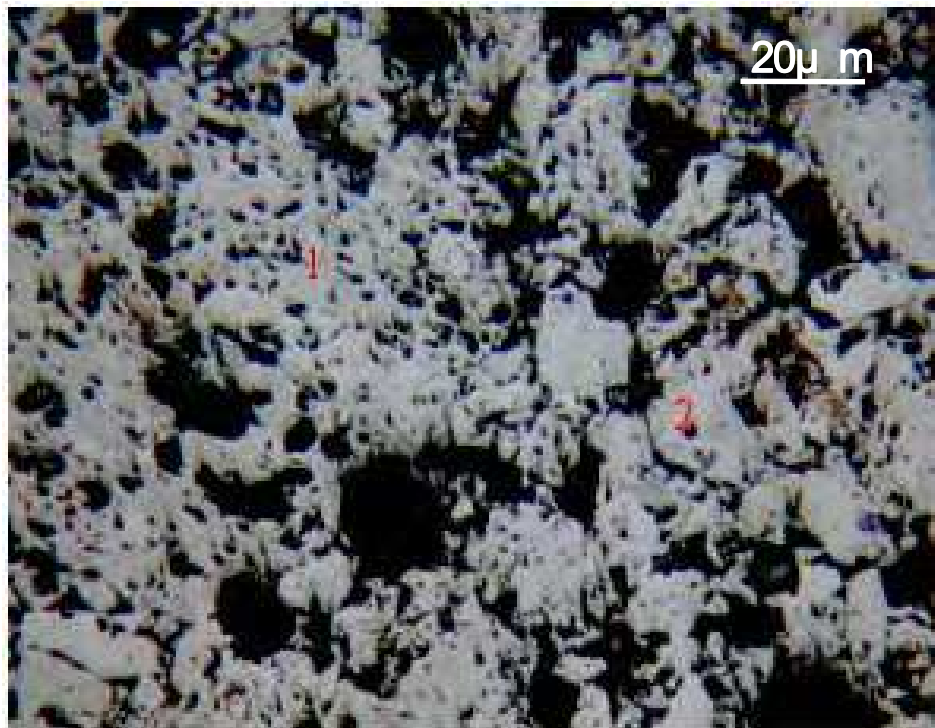


1-SH particle; 2-OH particle

Fig. 7. OH grains enclosed by or connected with SH grains in the pellet roasted at 1150°C

As shown in Fig. 7, a large number of junctions between particles are formed by recrystallization of Fe_2O_3 at 1150°C and the strength of the roasted pellet highly increases. However, the inner structure and shape of the OH particles remain visible, which indicates

that none of Fe_2O_3 recrystallization takes place in the OH particles at 1150°C . The junctions between particles come from Fe_2O_3 crystallization of the SH particles.



1-SH particle; 2-OH particle

Fig. 8. Recrystallization of Fe_2O_3 in the pellet roasted at 1230°C

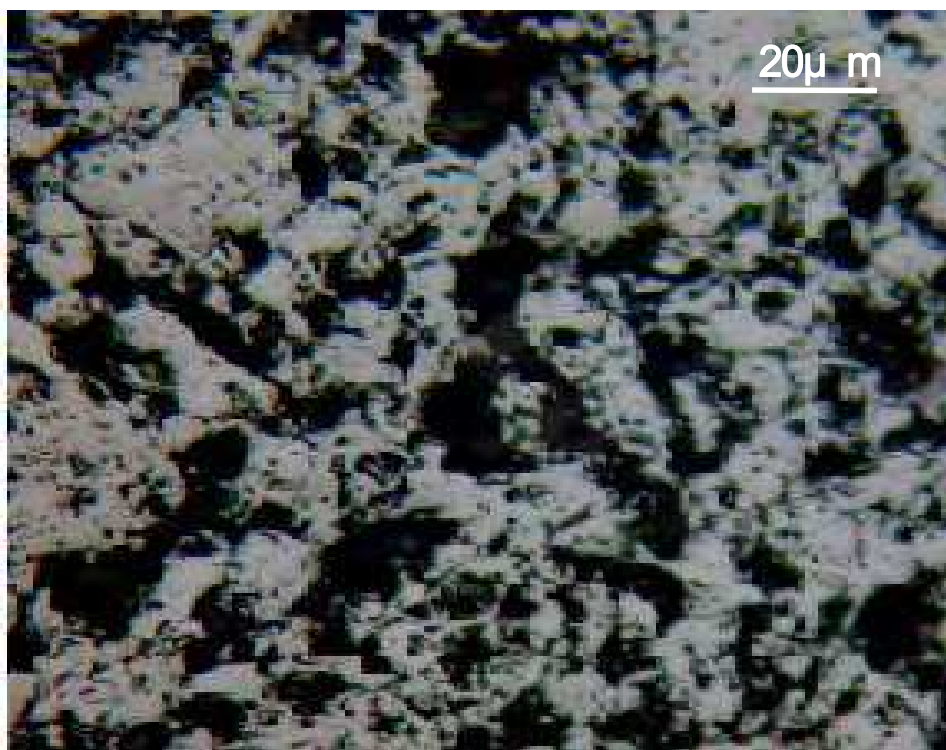


Fig. 9. Developed Fe_2O_3 recrystallization in the pellet roasted at 1280°C

At 1230°C (Fig. 8), Fe_2O_3 recrystallization is further developed and the interconnection between particles has been enhanced, and individual particles are scarce in pellet. The OH particles have been connected with or even enclosed by SH particles, and the strength of pellet is further increased. However, the inner structure of the OH particles are still compact, with marked difference from the SH particles, which suggests that recrystallization of Fe_2O_3 in the OH particles is still undeveloped at 1230°C, and the junctions between particles are from the Fe_2O_3 recrystallization of SH particles mainly.

At 1280°C, it can be seen from Fig. 9 that Fe_2O_3 recrystallization in the OH particles develops satisfactorily; all of hematite particles become porous, the profile of the OH particles almost disappears, and all the particles (both SH and OH) are connected with each other through Fe_2O_3 recrystallization and form a whole crystal structure; therefore, the strength of pellet is further improved.

In summary, the results indicate that Fe_2O_3 from SH and OH particles have different activities during roasting, which results in the difference of strength formation mechanisms of the mixed H/M concentrates pellets at various roasting temperatures. At lower temperature (1150°C), the pellet strength is mainly provided by Fe_2O_3 recrystallization of the SH particles. However, OH particles can be connected with the SH particles through crystal bridges formed by high activity Fe_2O_3 of SH particles, or even enclosed by the SH particles. So, OH particles also contribute to the pellet strength to a certain degree.

When the temperature goes up to 1250°C, Fe_2O_3 recrystallization in the SH particles is further developed, and the crystal junctions between the particles become stronger. However, Fe_2O_3 recrystallization within OH particles does not obviously take place, and few joint is formed between the close OH particles. Pellet strength is mainly provided by Fe_2O_3 recrystallization junctions of SH particles.

At 1280°C, Fe_2O_3 recrystallization in the SH and OH particles simultaneously occurs, and the joints between the close particles, including OH and SH, are well developed. Particles are connected with each other and the roasted pellet forms a whole crystal structure. The Fe_2O_3 recrystallization of SH and OH particles plays a crucial role in improving the roasted pellet strength.

The results indicate that, because the activity of Fe_2O_3 in the SH grains is higher than that in the OH grains, Fe_2O_3 recrystallization bonds between particles can be enhanced by the SH grains during preheating and roasting, thus the newborn SH is able to improve the pellet strength and decrease the roasting temperature of mixed H/M concentrates pellet. It is the reason that adding a certain proportion of magnetite concentrate is for the enhanced roasting performance of hematite pellet.

3. Fe_2O_3 recrystallization during the firing of carbon-burdened hematite pellet

3.1 Materials and methods

3.1.1 Materials

The hematite concentrate is characterized by high total iron grade (67.2% TFe) and less impurities (Table 3). The particle size is 92% undersize 0.074mm and the specific surface area is 1629.5cm²/g (Table 4).

Anthracite powder was used as the material of burdened carbon, of which the specific surface area reaches 6599 cm²/g after grinding.

Materials	Fe _{total}	FeO	SiO ₂	CaO	MgO	Al ₂ O ₃	LOI*
Hematite	67.22	0.55	2.17	0.01	0.05	0.55	0.59
Anthracite	1.48	/	6.86	1.51	0.24	5.88	84.08
Bentonite	7.07	/	60.61	0.94	2.2	17.98	10.41

*LOI-Loss on ignition

Table 3. Chemical compositions of the materials / %

+0.074mm/ %	0.074-0.045mm/ %	-0.045mm/ %	specific surface area/cm ² .g ⁻¹
7.79	28.99	63.22	1629.5

Table 4. Size distribution and specific surface area of hematite concentrate

3.1.2 Methods

For each test, 5 kg of hematite concentrate was blended with the given proportion anthracite powder, using 1.25% bentonite as binder. The green balls were prepared in a disc pelletizer with a diameter of 1000 mm, and the green balls with 9~15 mm in diameter were statically dried at 105°C in a drying oven for 4 hours.

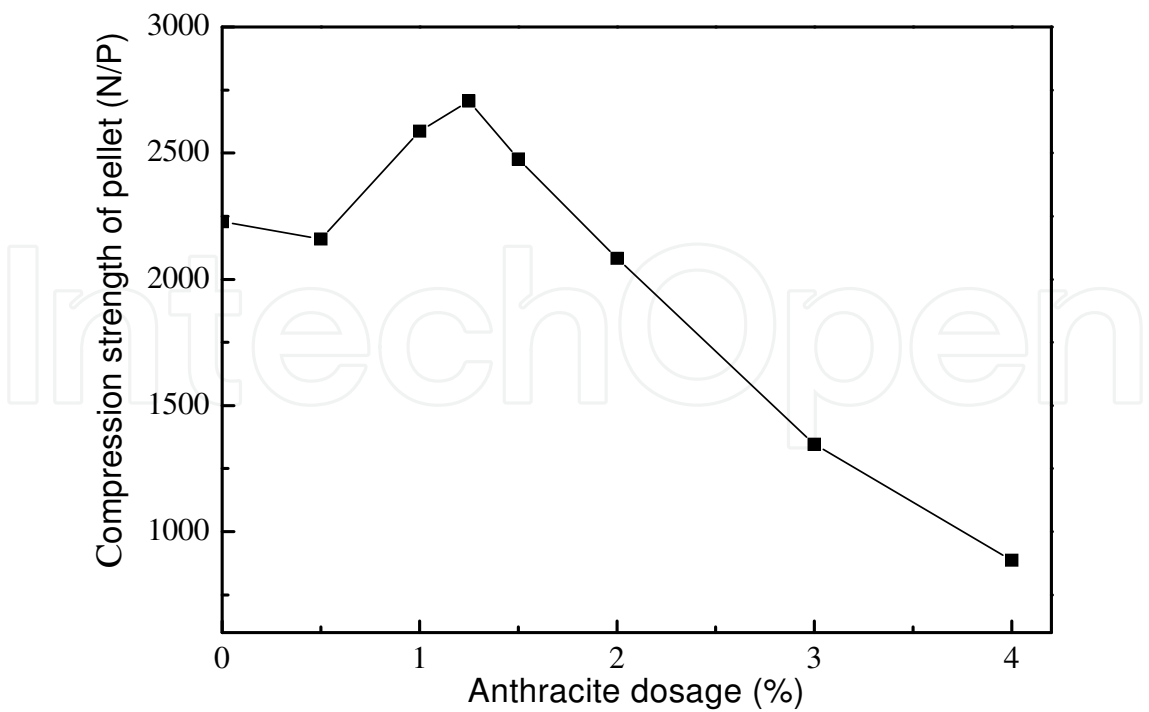
Firing teats were carried out in an electrically heated shaft furnace. To simulate firing atmosphere, mixed gas of N₂/O₂ at the given oxygen partial pressure (volume fraction) was pumped into the shaft furnace at a certain flow-rate. The dry balls were charged into heat-resistant pot, and then the pot was pushed downwards into the furnace step by step. The pellets were fired at the given temperature for a given period. Afterwards, the roasted pellets were taken out and naturally cooled to ambient temperature. The compression strength of cooled pellets was measured with an LJ-1000 material experimental machine. An average value of 10 pellets is expressed as the compression strength for each test.

3.2 Firing characteristics of carbon-burdened hematite pellet

3.2.1 Effects of anthracite dosage on compression strength

The effects of anthracite dosage on the compression strength of the roasted pellets are shown in Fig. 10.

As shown in Fig. 10, the pellet strength with 0.5% anthracite is a little lower than that with no anthracite. When anthracite dosage reaches 1.0%~1.25%, the compression strength goes up to the maximum, however, the strength decreases greatly if the anthracite further increases from 1.5% to 4%. The results indicate appropriate anthracite amount of 1.0%~1.25% may improve the strength of hematite pellet.

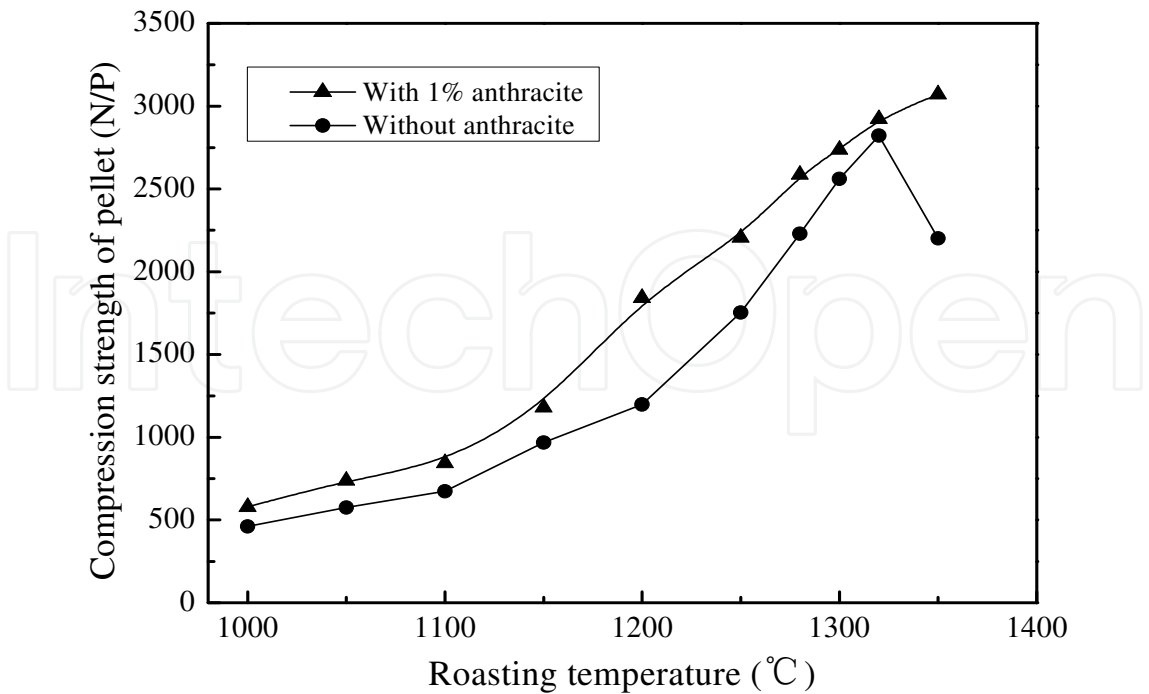


(Oxygen partial pressure: 20%, airflow: 6L/ min, roasting temperature: 1280°C, roasting time: 20min)

Fig. 10. Effects of anthracite dosage on the compression strength of pellet

3.2.2 Effects of roasting temperature on compression strength

The effects of roasting temperature on compression strength of pellet are shown in Fig. 11.



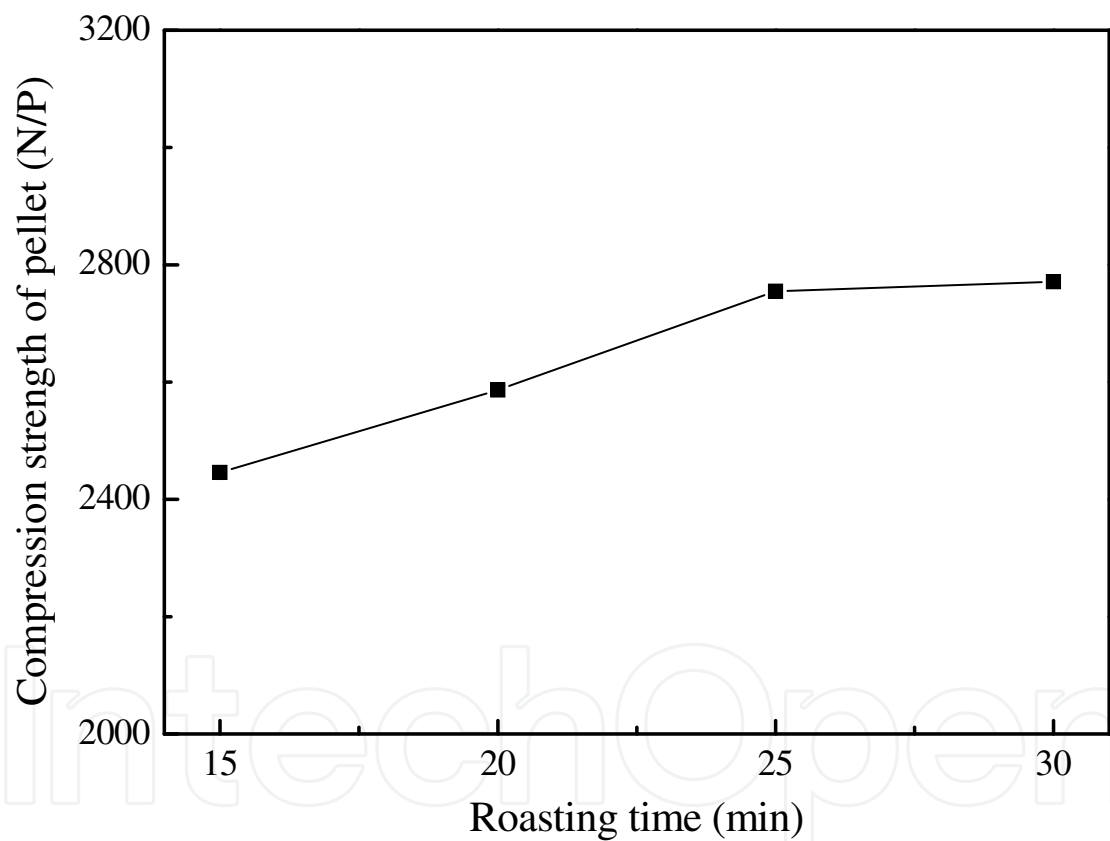
(Oxygen partial pressure 20%, airflow: 6L/ min, roasting time: 20min)

Fig. 11. Effects of roasting temperature on the compression strength of pellet

As shown in Fig.11, the strength of carbon-burdened pellet is always higher than that of pellet without carbon when roasted at the same temperature; moreover, for carbon-burdened hematite pellet, the compression strength increases constantly with the temperature. However, the strength of pellet in the absence of carbon not only doesn't increase markedly until 1250°C, but also decreases over 1320°C due to the decomposition of Fe_2O_3 . The results imply that the roasting temperature can be decreased and the firing temperature range is enlarged by adding an appropriate amount of anthracite into hematite pellet.

3.2.3 Effects of roasting time on compression strength

The compression strength of roasted pellet increases gradually with the roasting time prolonging and a maximum strength is obtained at 25 min (in Fig.12), hereafter, the strength almost remains constant.

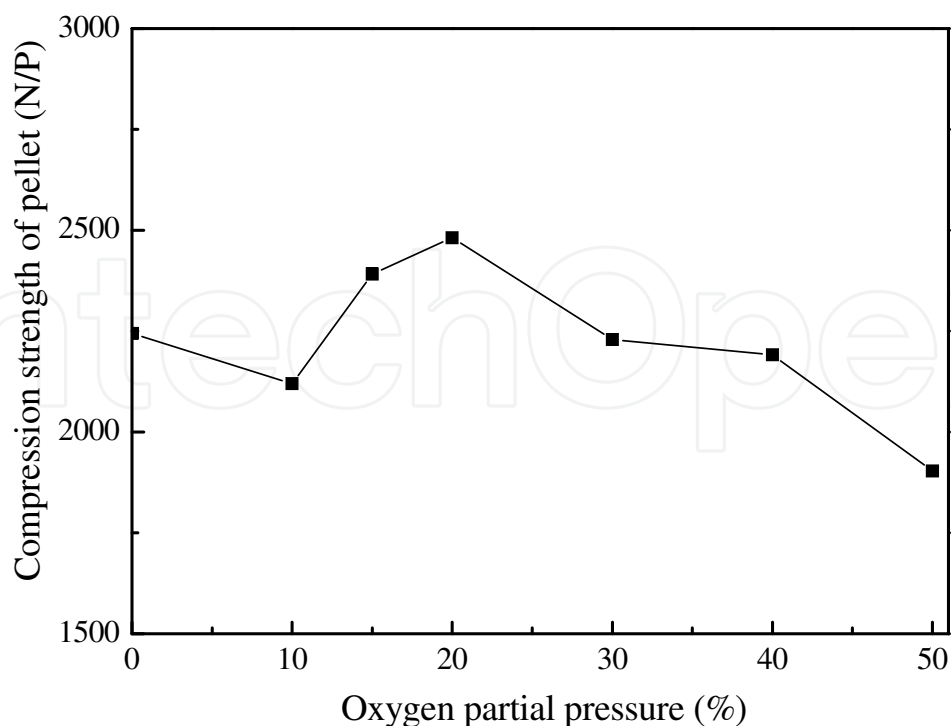


(Oxygen partial pressure: 20%, airflow: 6L/ min, roasting temperature: 1280°C, anthracite: 1.0%)

Fig. 12. Effects of roasting time on the compression strength of carbon-burdened pellet

3.2.4 Effects of oxygen partial pressure on compression strength

The compression strength of pellet is susceptible to the change of oxygen partial pressure as shown in Fig.13. The strength of the pellet roasted in N_2 , that is, in the inert atmosphere, is slightly higher than that in 10% O_2 . The strength nearly reaches the maximum at 20% O_2 , and then decreases gradually with increasing the oxygen partial pressure.



(Airflow: 6L/min, roasting temperature: 1280°C, roasting time: 20min, anthracite: 1.0%)

Fig. 13. Effects of oxygen partial pressure on the compression strength of carbon-burdened pellet

3.3 Roles of burdened carbon during the roasting

To shed light on the effects of the burdened carbon on the induration of hematite pellet, a test, as shown in Fig. 14, was designed to identify the reduction and decomposition of hematite in carbon-burdened pellet during roasting.

As shown in Fig. 14, a cylinder was made by briquetting hematite concentrate firstly, the cylinder bottom is closed, and its inner diameter is 20 mm, the outer diameter is 30 mm. To allow the gas upward injecting into the inner cylinder and penetrating through the anthracite powder layer, many ventages with 0.1 mm diameter were drilled through the cylinder bottom.

Dry pellets with 2~3 mm in diameter were prepared from hematite concentrate in advance, and then were charged into the surface layer of inner cylinder. The cylinder bottom, anthracite powder layer and pellet layer were separated by inert material of Al_2O_3 powder to avoid their contact with each other.

At the beginning of trial, the sample prepared according to Fig. 14 was placed in an electrically heated shaft furnace, and 6L/min N_2 with 99.99% purity was pumped into the shaft furnace from the bottom. The sample was taken out and immersed into water immediately after roasted at 1280°C for 20 minutes. Subsequently, the FeO content of the cylinder bottom and pellet was measured respectively.

It is shown that FeO content of the cylinder bottom and pellet is 4.35% and 28.69% respectively. FeO content of the pellet is obviously higher than that of the cylinder bottom.

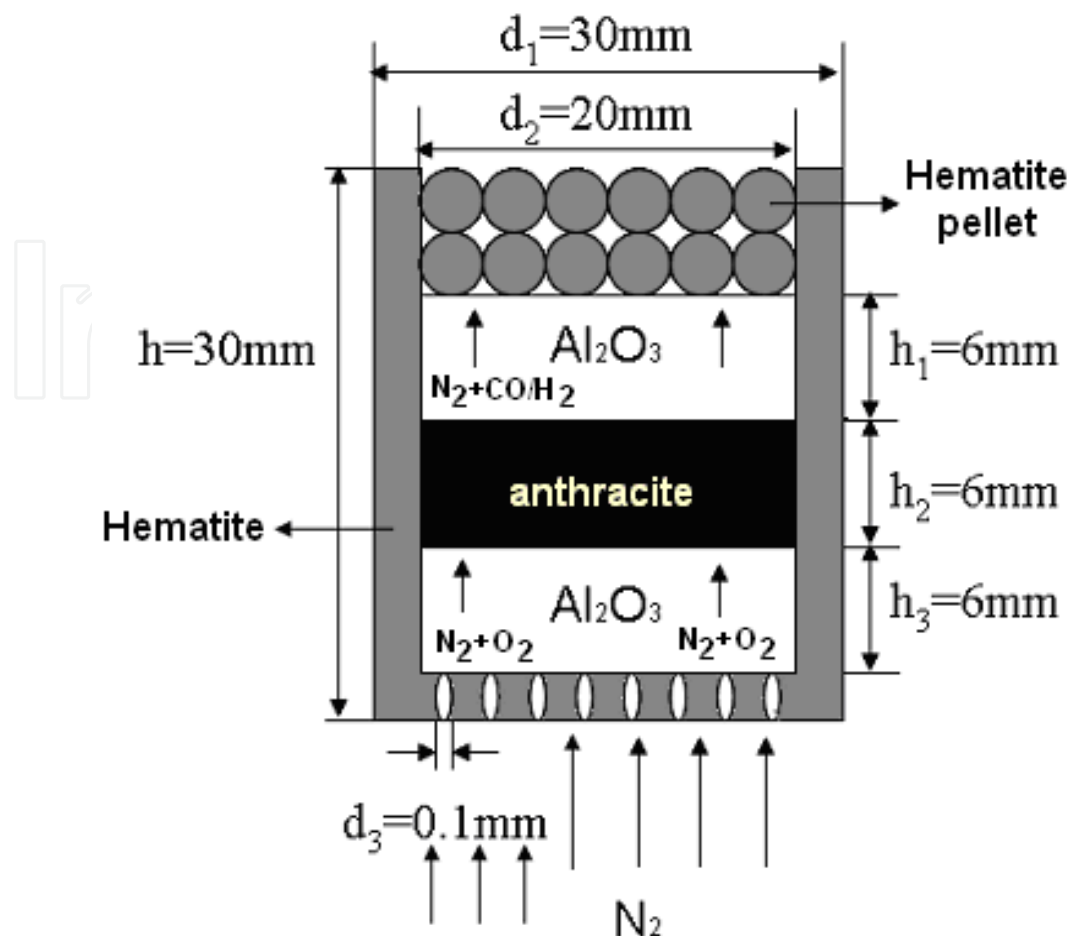


Fig. 14. Schematic diagram of the test on the role of burdened carbon during roasting

In N_2 atmosphere, hematite may decompose into magnetite and release O_2 according to formula (1), and FeO content increases accordingly. It is the reaction that the hematite within the cylinder bottom occurs. However, because of being separated by Al_2O_3 powder, the hematite within the cylinder bottom can't be reduced by anthracite or upwards flowing reductive gases CO/H_2 , which are produced by gasification of anthracite. Therefore, the increase of FeO content in the cylinder bottom is only caused by the decomposition of hematite.

However, as regards as the hematite within the pellet, on one hand, it may be decomposed into magnetite in N_2 gas as same as the hematite within the cylinder bottom; on the other hand, it can be also reduced into magnetite by upwards flowing CO/H_2 produced by gasification of anthracite. Therefore, the increase of FeO content of the pellet is caused by both the decomposition and the reduction of hematite, and the latter is more crucial.

The above results identify that the burdened carbon plays the role of reductant during the roasting, and a large number of newborn magnetite are created due to the reductive reaction of hematite by CO/H_2 , the products of gasification of anthracite.

Of cause, the burdened carbon can release heat via combustion and heat up the inner pellet, which is advantageous for the induration of hematite pellet. The heating function of the burdened carbon resembles the heat release by oxidation of the magnetite concentrate added into hematite pellet.

3.4 Induration mechanisms of carbon-burdened hematite pellet

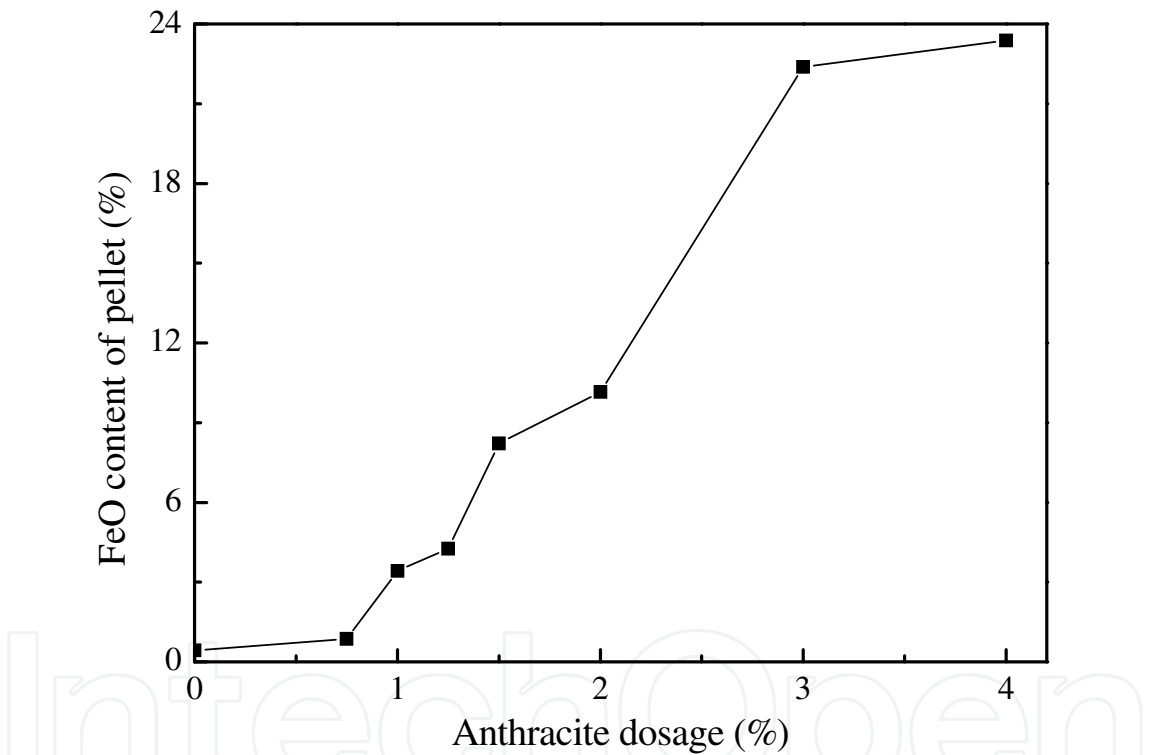
3.4.1 Changes of FeO content during the roasting of carbon-burdened pellet

3.4.1.1 Effects of anthracite dosage

FeO content of the roasted pellets with different dosage of anthracite is measured by chemical analysis and the results are shown in Fig. 15.

As shown in Fig.15, the FeO content of the roasted pellets increases gradually with the increasing the dosage of anthracite. This suggests that the anthracite in pellet benefits the reduction of hematite during roasting. Because of the relatively strong reductive atmosphere under the condition of high dosage of anthracite, a large amount of Fe₂O₃ is reduced into Fe₃O₄.

The above results that FeO content of the pellet varies with the anthracite dosage are in accord with the conclusions obtained from the tests as shown in Fig. 14



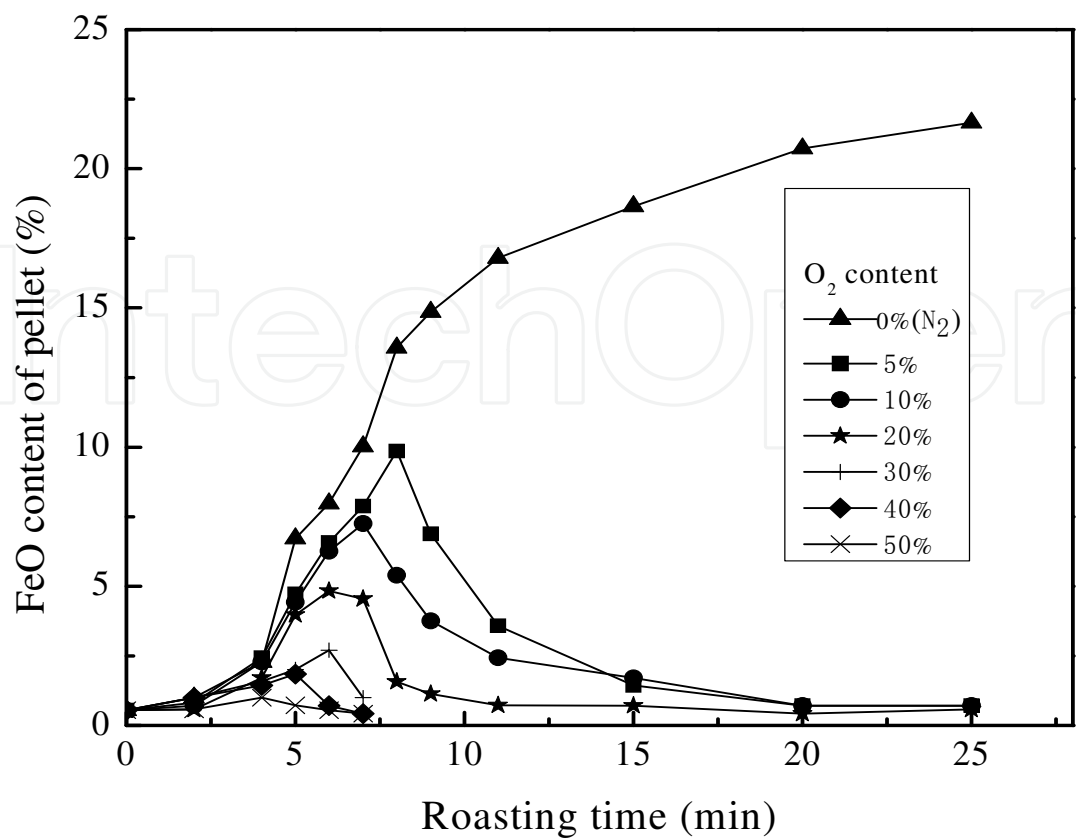
(Oxygen partial pressure: 20%, airflow: 6L/ min, roasting temperature: 1280°C, roasting time: 6min)

Fig. 15. Effects of anthracite dosage on FeO content of the carbon-burdened pellet

3.4.1.2 Effects of oxygen partial pressure

FeO content of the pellets roasted at different oxygen contents is measured and the results are shown in Fig. 16.

As shown in Fig.16, the reduction of hematite mainly occurs at the initial roasting stage. The time, when the maximum FeO content attains to, is shortened with increasing the oxygen partial pressure, which indicates that the increase of oxygen partial pressure has favourable effect on oxidization rate of newborn magnetite.



(Anthracite: 1.0%, airflow: 6L/min, roasting temperature: 1280°C)

Fig. 16. Change of FeO content of the pellets roasted at different oxygen partial pressures for different period

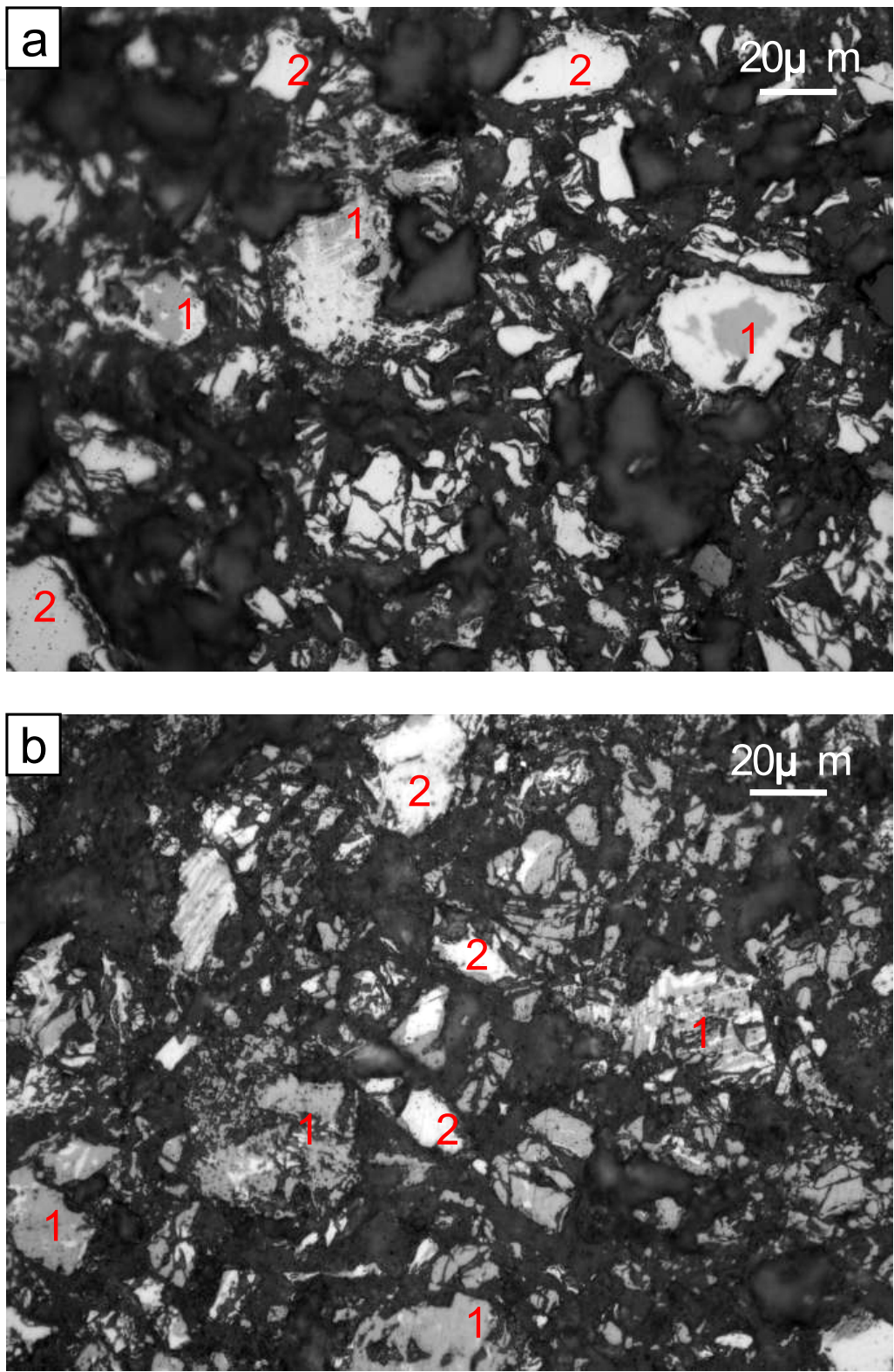
The maximum FeO content decreases when the carbon-burdened hematite pellet is roasted at high oxygen partial pressure. The result shows that the lower the oxygen partial pressure during roasting, the stronger the reductive atmosphere within the pellet; and the reduction of Fe_2O_3 can be enhanced. At high oxygen partial pressure, the burdened carbon in pellet combusts completely, and more carbon comes into being not CO but CO_2 , thus reductive atmosphere is weakened, which prevents the hematite from reducing into magnetite.

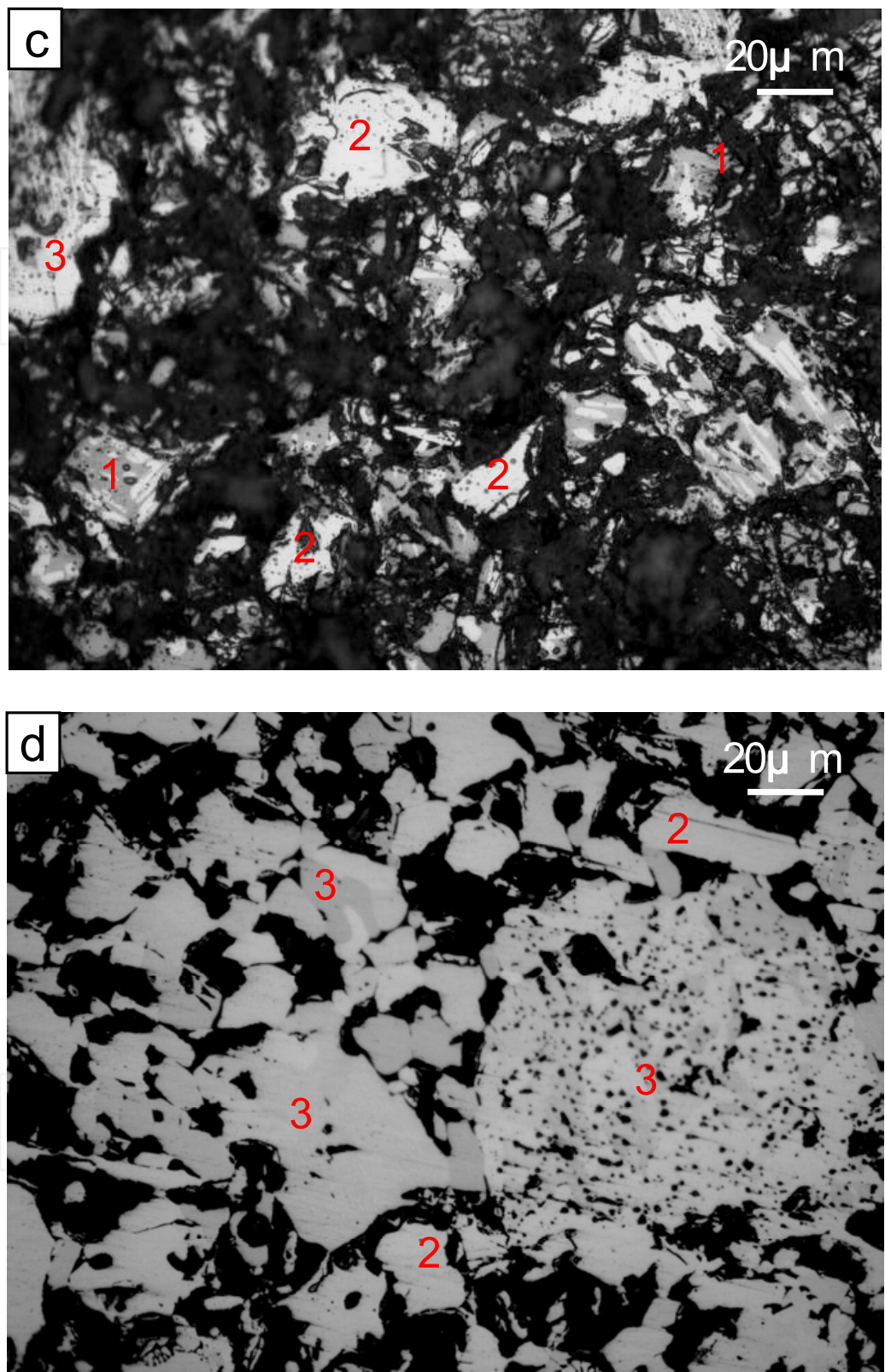
In oxidative atmosphere, FeO content of the pellet increases firstly and then decreases during roasting, the reason for which is that, at the initial roasting stage, the reduction rate of hematite into magnetite is higher than the oxidation rate of newborn magnetite into hematite, however, accompanied with the consumption of burdened carbon, the reduction rate decreases while the oxidation rate increases, the maximum FeO content attains when the reduction rate equals to the oxidation rate. Subsequently, FeO content decreases alone with the oxidation of magnetite untill the oxidation is complete.

It indicates that some original hematite (OH) can be reduced to magnetite by the burdened carbon firstly, and then the newborn magnetite is oxidized into secondary hematite (SH) again during the roasting. The transformation of OH to magnetite and newborn magnetite to SH changes the route of Fe_2O_3 recrystallization during the induration of carbon-burdened hematite pellet.

3.4.2 Fe₂O₃ recrystallization behaviours of carbon-burdened hematite pellet

To shed light on the Fe₂O₃ recrystallization behaviour, the microstructure of carbon-burdened hematite pellets at different roasting stage is investigated and the results are presented in Fig. 17.





Roasting time: a-4min; b-6min; c-8min; d-20min
1-Magnetite; 2-OH ; 3- SH
(Anthracite: 1.0%, Oxygen partial pressure: 20%, airflow: 6L/min)

Fig. 17. Microstructure of the carbon-burdened pellets roasted at 1280°C

When the volatile matter in anthracite is pyrolyzed and gasified during initial roasting stage, the reduction atmosphere is gradually enhanced within the pellet, and a few magnetite grains, shown in Fig. 17a, are formed by the reduction of OH. An apparent colour difference can be observed between the hematite grains and magnetite grains. The hematite presents bright and white colour, while the magnetite is grey. However, the OH particles keep their original shape and discernible angularity. The inner crystal structure of OH is compact and there is no crystal bond formed between OH particles.

It can be seen from Fig. 17b, a large amount of newly created magnetite is observed as the roasting process progresses; however, the OH particles keep their original shapes, and there is no crystal junction observed still.

As shown in Fig. 17c, the content of newborn magnetite decreases, and a few SH, which comes from the oxidation of the newborn magnetite, are formed. In comparison with OH grains, the angularities of the SH particles become unclear, and a few crystal junctions can also be observed between them. In this stage, with the consumption of anthracite, reduction atmosphere is weakened and oxidation rate of SH is accelerated.

At the end of roasting, the newborn magnetite has been completely oxidized into SH, and a large number of crystal junctions between particles are formed (as shown in Fig. 17d). Pellet strength is mainly provided by Fe_2O_3 recrystallization junctions between SH particles and OH particles.

It can be concluded from the results mentioned above that partial OH particles can be reduced firstly and turn into magnetite particles by the anthracite powder dispersed in the carbon-burdened hematite pellet, however, the newborn magnetite can be subsequently oxidized into SH particles with higher activity, and the route of Fe_2O_3 recrystallization is changed from the recrystallization of OH particles to the recrystallization bonds among SH particles and OH particles. Therefore, the formation of SH during the roasting of carbon-burdened hematite pellet is able to improve the pellet strength and decrease the roasting temperature. It is the reason why adding a certain proportion anthracite is also an effective way to enhance the roasting performance of hematite pellet.

4. Conclusions

Both magnetite and burdened carbon are found to be the favourable techniques for enhancing the induration of hematite pellet. The induration mechanisms of hematite pellet with addition of magnetite concentrate and anthracite powder are revealed by characterization of Fe_2O_3 recrystallization rules during the oxidization roasting.

The crystallization behaviours of Fe_2O_3 during preheating and roasting of pellets made from mixed hematite/magnetite (H/M) concentrates have been revealed. The results indicate that the strength of pellet is mainly provided by the crystalline connections between the particles during preheating. This occurs because the activity of Fe_2O_3 from secondary hematite (oxidized from magnetite concentrate) is higher than that from original hematite (from the raw hematite concentrate). In the roasting process, when temperature is lower than 1250°C , the strength is mainly provided by the development, connection and growth of Fe_2O_3 crystalline grains from secondary hematite. Only if the temperature exceeds 1280°C does Fe_2O_3 recrystallization in original hematite grains develop very well.

Because the activity of Fe_2O_3 in the secondary hematite grains is higher than that in the original hematite grains, Fe_2O_3 recrystallization bonds between particles can be enhanced by the secondary hematite grains during preheating and roasting, and the secondary hematite in H/M concentrate pellet is able to improve the strength and decrease the roasting temperature of hematite pellet. Thus, adding a certain proportion of magnetite concentrate is an effective way to improve the roasting performance of hematite pellet.

The effects of anthracite on oxidation roasting behaviour for hematite pellet have been elucidated. Anthracite in pellet has two functions: the one lies on that a part of heat needed in roasting process can be supplied by the carbon combustion, and the other is that the reduction of partial hematite by the carbon dispersed in pellet, as well as the partial decomposition of hematite at relatively low oxygen partial pressure, leads to the transformation of hematite into magnetite during the roasting.

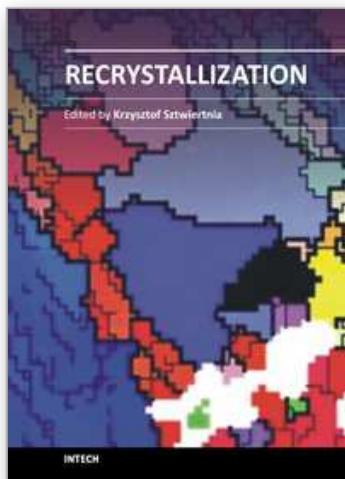
Based on microstructure analysis, it can be founded that the new-born magnetite, produced from the reduction and the decomposition of original hematite (OH), is oxidized into the secondary hematite (SH) during roasting. Thus, Fe_2O_3 recrystallization bonds between particles can be consolidated by the secondary hematite grains at lower roasting temperature. The strength of carbon-burdened hematite pellet is enhanced and the roasting temperature is decreased due to the formation of secondary hematite. Therefore, adding a certain proportion of anthracite is also an effective way to enhance the roasting performance of hematite pellet.

5. Acknowledgments

The authors want to express their thanks to National Science Fund for Distinguished Young Scholars (50725416), National Natural Science Foundation of China (50604015 and 50804059) and Fundamental Research Funds for the Central Universities for financial supports of this research. Dr. Mingjun Rao is appreciated for his helpful remarks on spelling and expression.

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Recrystallization

Edited by Prof. Krzysztof Sztwiertnia

ISBN 978-953-51-0122-2

Hard cover, 464 pages

Publisher InTech

Published online 07, March, 2012

Published in print edition March, 2012

Recrystallization shows selected results obtained during the last few years by scientists who work on recrystallization-related issues. These scientists offer their knowledge from the perspective of a range of scientific disciplines, such as geology and metallurgy. The authors emphasize that the progress in this particular field of science is possible today thanks to the coordinated action of many research groups that work in materials science, chemistry, physics, geology, and other sciences. Thus, it is possible to perform a comprehensive analysis of the scientific problem. The analysis starts from the selection of appropriate techniques and methods of characterization. It is then combined with the development of new tools in diagnostics, and it ends with modeling of phenomena.

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Guanghui Li, Tao Jiang, Yuanbo Zhang and Zhaokun Tang (2012). Recrystallization of Fe₂O₃ During the Induration of Iron Ore Oxidation Pellets, Recrystallization, Prof. Krzysztof Sztwiertnia (Ed.), ISBN: 978-953-51-0122-2, InTech, Available from: <http://www.intechopen.com/books/recrystallization/recrystallization-of-fe2o3-during-the-induration-of-iron-ore-oxidized-pellets->

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