

EFFECT OF HIGH MgO/Al₂O₃ RATIO (1.2 TO 2.2) ON SINTERING BEHAVIOR AND METALLURGICAL PROPERTIES

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Abstract

The sintering pot test was used to investigate the effect of MgO/Al₂O₃ ratio in the range of 1.2 to 2.2 on the sintering behavior of iron ore. The main characterization methods of X-ray diffraction (XRD) and scanning electron microscopy-energy disperse spectroscopy (SEM-EDS) were employed. The results showed that the strength, yield, and reducibility of sinter initially increased and then decreased with increasing MgO/Al₂O₃ ratio from 1.2 to 2.2. The index would reach the peak value with the strength of 70.6% and the yield of 83.81%, respectively, when MgO/Al₂O₃ ratio was 1.8. The reduction index would reach the peak value of 88.54% with MgO/Al₂O₃ ratio of 1.6. The FeO content, solid fuel consumption, and the RDI_{+3,15} of sinter increased dramatically with increasing MgO/Al₂O₃ ratio. When MgO/Al₂O₃ ratio was up to 2.2, the solid fuel consumption and RDI_{+3,15} reached a maximum value of 61.93 kg/t and 96.1%, respectively. The form of SFCA was acicular when MgO/Al₂O₃ ratio was less than 1.6 and then transformed to plate-like which content also reduced. The magnetite increased while hematite decreased with enhancing MgO/Al₂O₃ ratio.

Keywords: MgO/Al₂O₃ ratio; Sintering; Strength; Metallurgical properties

1. Introduction

Sinter ore is one of the main charge materials in blast furnace (BF) operation [1]. Productivity of blast furnace is governed by the sinter qualities such as reducibility and mechanical strength, which could decrease the fuel rate of ironmaking in a BF and provide iron-rich raw material with a suitable porosity to facilitate the smooth operation of BF [2]. Owing to the rapid development of iron and steel industry, demand for the iron-containing raw materials of the production of sinter is expected to increase substantially [3]. Therefore, more of the lower grade iron ore imported from Australia and Brazil has been used in ironmaking process [4]. Nowadays, the utilization of low grade iron ore with high-alumina has matured in steel enterprises, while the usage of high-magnesium ore is relatively limited. There are large amounts of high-magnesium iron ore in China and Egypt. These ores are not widely used in raw materials of sinter due to the adverse effect on sinter properties, such as the fuel rate, and sinter strength and reducibility deteriorate with an increase of MgO [5]. The MgO/Al₂O₃ ratio, as one of the indicators for evaluating the quality of iron ore, is conventionally expected to be less than 1.3 [6]. However, the

MgO/Al₂O₃ ratio of these high-magnesium iron ores is up to 2.2. and its influence on the sintering characteristics are not clear so far. In order to improve the utilization rate of this kind of high-magnesium ore and expand its ratio in sintered iron-containing raw materials, it is of great significance to study the effect of high MgO/Al₂O₃ ratio on sinter performance.

In recent years, many investigations on the effects of MgO and Al₂O₃ on sintering behavior have been carried out [7-12]. Kalenga and Garbers-Craig [13] and Hsieh [14] investigated the effects of gangue, including MgO, on the sintering characteristics, mineralogy, and properties of sinter and found that the MgO·Fe₂O₃ existed in sintered ore with the increase in MgO content in sintering materials. According to Dong et al. [15], Al₂O₃ had an adverse effect on the sinter strength and productivity. Sinter reducibility reduced firstly and then gradually improved, while the low temperature reduction degradation performance showed an opposite trend with increasing Al₂O₃ content. Wang et al. [16] indicated that the calcium ferrite intertwined with magnetite, and the sinter reducibility, as well as low temperature reduction degradation performance, improved when MgO/Al₂O₃ ratio was in the range of 1.06 to 1.22. Based on the literature review, whether it is a single

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MgO and Al_2O_3 or the interaction of MgO and Al_2O_3 , this will have a certain impact on the quality of the sinter. However, previous studies have focused on the effects of low-w(MgO) ore and low MgO/ Al_2O_3 ratio (<1.3) on sinter behavior. The work pertaining to the behavior of high MgO/ Al_2O_3 ratio (>1.3) on sinter behavior is very limited.

Therefore, the sintering pot tests were carried out in laboratory to reveal the effect of high MgO/ Al_2O_3 ratio (1.2 to 2.2) on sintering behavior and metallurgical properties under the condition of a certain amount of fuel. The influence mechanism of MgO/ Al_2O_3 ratio on sinter strength, microstructure, reducibility, and low temperature reduction degradation performance was emphatically analyzed, which would provide guidance for iron and steel industry production.

2. Experimental

2.1 Raw materials

Iron ore fines, limestone, dolomite, quicklime, coke breeze, and sinter return were taken from a steel plant in China for the sintering pot test. The chemical composition of the raw materials and coke breeze are listed in Table 1 and Table 2, respectively. The iron grade of ore 1, ore 2, and ore 3 was 52.01%, 62.22%, and 58.62%, respectively. Ore 2 had the lowest FeO content of 0.31% compared with ore 1 of 17.17% and ore 3 of 15.95%. The content of SiO_2 and CaO in ore 1 and ore 3 was higher than that of ore 2. The sinter MgO content was adjusted by adding different proportion of dolomite. Limestone and quicklime were used as flux in sintering. It can be seen from Table 2 that the fixed carbon of the coke breeze reached 83.96% and the volatile value was 0.82%.

Table 1. Chemical compositions of the raw materials (mass percent, %)

Raw materials	TFe	FeO	SiO_2	CaO	Al_2O_3	MgO	LOI
Ore1	52.01	17.17	8.52	1.36	1.22	3.17	7.26
Ore2	62.22	0.31	3.46	0.28	1.96	0.08	4.45
Ore3	58.62	15.95	8.51	2.76	2.12	0.50	1.25
Dolomite	1.03	/	4.15	30.54	0.94	28.15	40.7
Limestone	0.29	/	1.52	52.09	0.65	0.53	42.0
Quicklime	0.79	/	2.18	89.72	0.84	1.06	5.5
Sinter return	52.7	/	6.90	12.4	1.50	2.30	/

Table 2. Industrial analysis of coke breeze and chemical compositions of ash (mass percent, %)

Fixed carbon	Volatile	Organic compounds	Ash (13.8)						Σ
			FeO	SiO_2	CaO	Al_2O_3	MgO	Others	
83.96	0.82	1.42	0.16	7.63	0.62	1.86	0.21	3.32	100

Also, the ash of coke breeze possessed lower content of CaO and MgO as well as higher content of SiO_2 and Al_2O_3 .

The laser particle size analyser (LA-950A2) was used to measure the size distributions of ore 1, ore 2, and ore 3. For the purpose of accuracy, each sample was tested three times. Figure 1 shows the particle

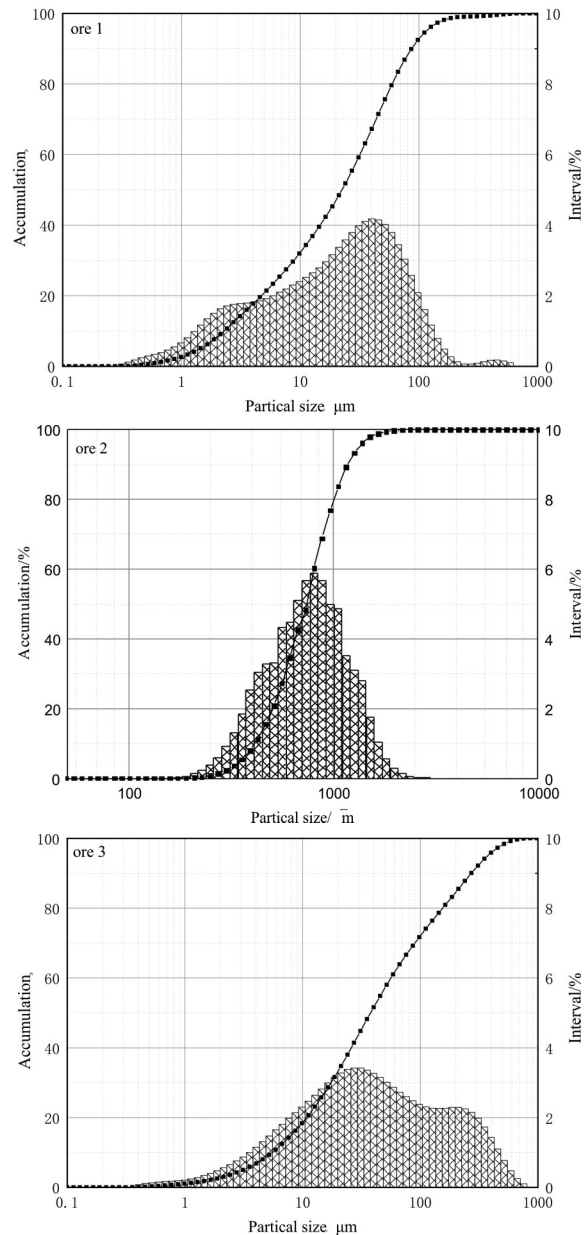


Figure 1. Size analysis of ore 1, ore 2 and ore 3

size distributions of the three ores. It is observed that the size of ore 2 was much larger than the sizes of both ore 1 and ore 3. Most of the ore 2 particles had size 1000 μm, while the median sizes of the ore 1 and ore 3 were in the range of 10-100 μm. For median size distribution and mean size distribution, the ore 2 was the largest, and the compound system showed a multimodal distribution, while the mean size of ore 1 was close to that of ore 3. The distribution intervals of ore 2 were much narrower than those of ore 1 and ore 3. The analysis of particle sizes of the three ores showed that the granulation effectiveness of ore 1 and ore 3 was better, while ore 2 had the worst granulation effectiveness.

Figure 2 shows the XRD analysis of ore 1, ore 2, and ore 3. It can be observed from the XRD results that the main phases of ore 1 and ore 3 were magnetite (Fe₃O₄), hematite (Fe₂O₃), and quartz (SiO₂). Besides, ore 1 also contained a small amount of siderite (FeCO₃). The main phase in ore 2 was hematite, indicating that ore 2 was typical hematite.

shown in Table 3. The mass fraction of quicklime was 3.0%, and the basicity (R=CaO/SiO₂) was 1.8. Return fines and coke breeze were 20% and 4.5%, respectively. Ore 2 as well as ore 3 were fixed at 5.0% and 15.0%. MgO/Al₂O₃ was adjusted to 1.2, 1.4, 1.6, 1.8, 2.0, and 2.2 by adjusting ore 1 and flux. Sinter blend mix used two-mixed granulation and the moisture was 8.8%.

Table 3. Sintering pot test scheme (mass percent, %)

Materials	S1	S2	S3	S4	S5	S6
Ore1	40.6	40.1	39.7	39.3	38.9	38.4
Ore2	5.00	5.00	5.00	5.00	5.00	5.00
Ore3	15.0	15.0	15.0	15.0	15.0	15.0
Dolomite	0	1.20	2.20	3.20	4.20	5.40
Limestone	11.9	11.2	10.6	10.0	9.40	8.70
Quicklime	3.0	3.0	3.0	3.0	3.0	3.0
Coke breeze	4.5	4.5	4.5	4.5	4.5	4.5
Sinter return	20	20	20	20	20	20
MgO/Al ₂ O ₃	1.2	1.4	1.6	1.8	2.0	2.2

2.2 Experimental method

The blend mix proportion of raw materials was

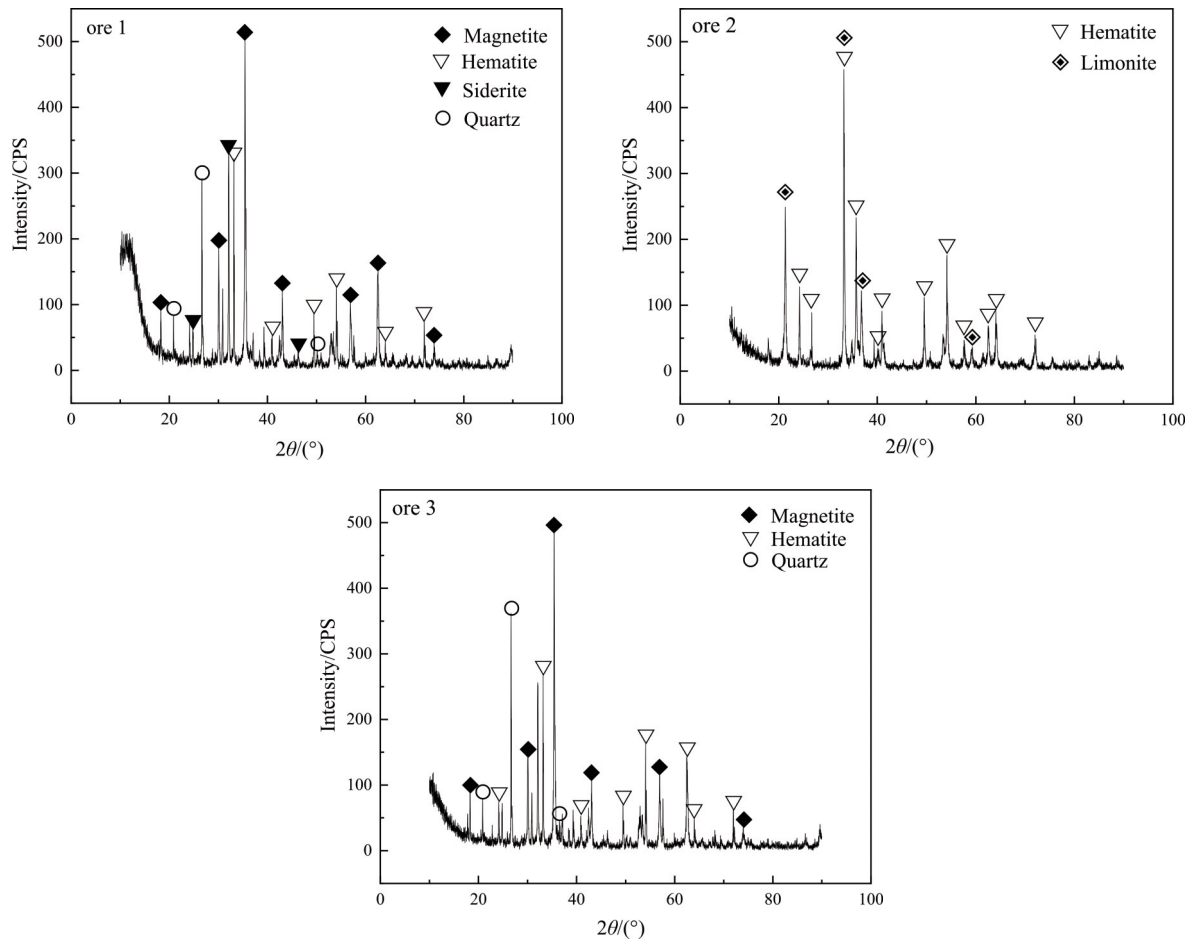


Figure 2. X-ray diffraction pattern of ore 1, ore 2 and ore 3



According to the experimental scheme (Table 3), the raw materials such as iron ore, flux, coke, and sinter return fines were mixed manually until well blended. The schematic diagram of the granulating process is presented in Figure 3. Then the sintering tests were performed in an experimental pot with a diameter of 285 mm, and a height of 500 mm, which is shown in Figure 4. The experimental set-up consisted of a sintering cup, an igniter, and an exhaust device. The sintering cup where the sintering process took place was composed of preheating zone, combustion zone, and sintering completion zone from bottom to top.

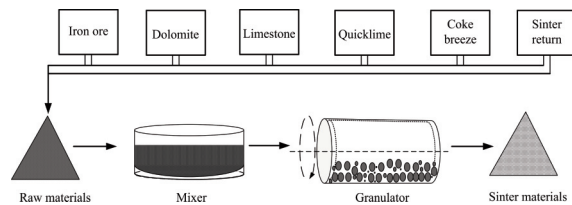


Figure 3. Schematic diagram of the granulating experiments

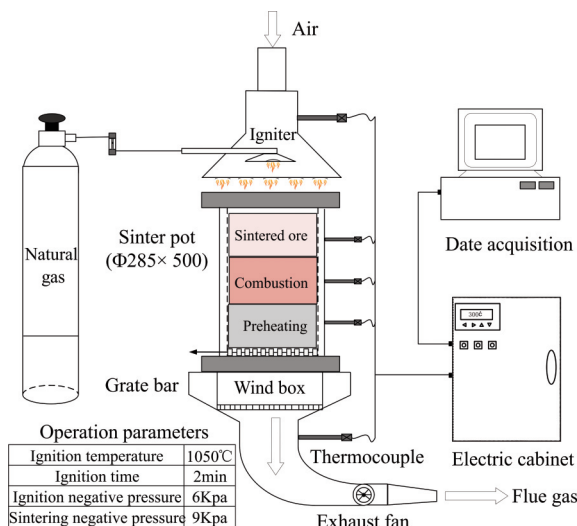


Figure 4. The diagram of laboratory pot grate sinter machine

The sintering tests covered blending, mixing, granulation, ignition, sintering, cooling, crushing, and treatment of cooled sinter. The mixed sintering raw material was loaded into the sinter pot after granulation. Then with ignition pressure at 1050°C was -6 kPa for 2 min, which was adjusted to -9 kPa in sintering process. Sintering proceeded until the end point of sintering when the temperature of flue gas reached the peak value. After sintering, the sinter was tumbled together for 8 minutes in an Abrasion tester. Then, the tumbled particles were screened to measure the tumble strength. The reducibility (RI) was determined using the ISO-4696 test procedure. This

test was carried out at an elevated temperature under a reducing gas atmosphere simulating blast furnace reduction condition. The low temperature reduction degradation (RDI) of the sinter was determined according to ISO-7215 [17].

A total of 2.0 g of each sample was ground into fine powder less than 50 μ m in an agate mortar for powder XRD determination. The mineral phase of samples was identified by Rigaku D/max2500/PC (Cu Ka) with scanning angular range of 10°~90° at a rate of 4 (°)/min. The XRD data were collected in continuous scanning mode. The micrographs of samples were obtained with a scanning electron microscope (SEM, Model TESCAN VEGA3 LMH) and the compounds were confirmed by energy-dispersive spectrum (EDS).

3. Results and discussion

3.1 Influence on sinter strength

One of the principal requirements for sintering process is high sinter strength to avoid the disintegration of the sinter in the upper part of the blast furnace and thus improve the permeability of the furnace burden [18]. The influence of MgO/Al₂O₃ ratio on sinter strength is plotted in Figure 5. The results show that there was a considerable effect of MgO/Al₂O₃ ratio on strength, which increased from 67.24% to 70.6% as MgO/Al₂O₃ ratio varied from 1.2 to 1.8 and then it reduced. When MgO/Al₂O₃ ratio was 2.2, the value of strength was the lowest with 63.65%. The main reason for the reduction of strength was that MgO and Al₂O₃ both had high melting point refractory, reducing the number of bonding phases generated during sintering under the condition of a certain amount of fuel.

3.2 Influence on FeO content and sintering process

The relationship between FeO content and

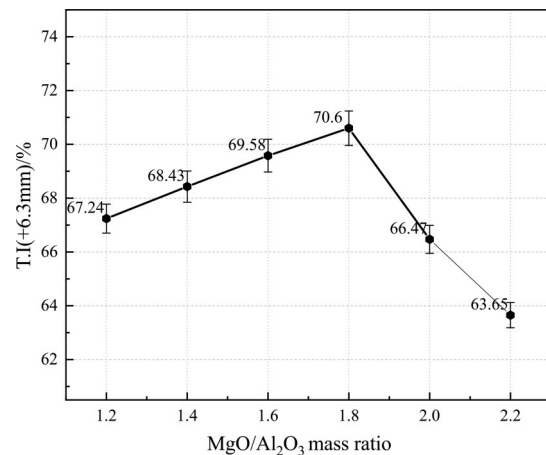


Figure 5. Influence of MgO/Al₂O₃ ratio on sinter strength

MgO/Al₂O₃ ratio is given in Figure 6. It can be observed that MgO/Al₂O₃ ratio had a significantly effect on the FeO content. The FeO content increased from 8.76% to 9.36% when MgO/Al₂O₃ ratio changed from 1.2 to 2.2. FeO content mainly depended on the magnetite phase present in the sinter [19]. Thus, the increase of FeO occurred mainly because the increase of MgO/Al₂O₃ ratio promoted the formation of magnetite (Fe₂O₃·FeO). In addition, the coke breeze ratio was constant from S1 to S6. The required heat amount could be decreased as limestone ratio decreased from S1 to S6. It means that much heat amount would be utilized for sintering reaction when MgO/Al₂O₃ ratio gradually increased, which led to the production of liquid phase that increased and the permeability became poor. Finally, the content of FeO in the sinter had increased.

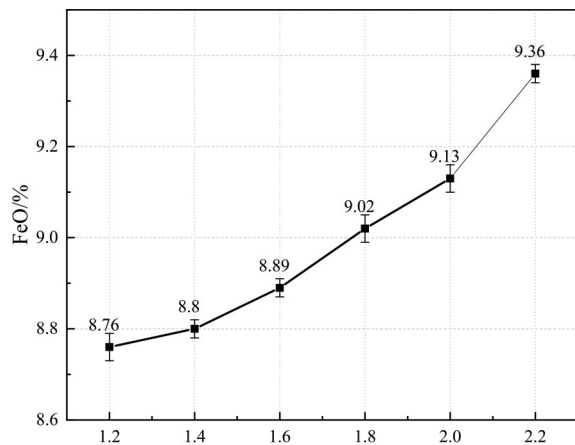


Figure 6. Influence of MgO/Al₂O₃ ratio on sinter FeO

In order to maintain a high percentage of sinter in the blast furnace burden and reduce sintering cost, it is desired to operate the sinter plant at higher level of yield and reduce the solid fuel consumption [18]. The effects of MgO/Al₂O₃ ratio on the yield as well as solid fuel consumption of sinter are displayed in Figure 7. The yield was calculated using the Equation (1):

$$Y = p / t \tag{1}$$

where Y is the yield of sinter (%), p is the mass of sinter whose particle size is larger than 5mm (kg), and t is the total mass of sinter (kg).

The solid fuel consumption was calculated using the Equation (2):

$$F = r / m \tag{2}$$

where F is the solid fuel consumption of sinter (kg/t); r is the mass of fuel added to the mixture (kg); and m is the mass of sinter whose particle size is

larger than 5mm (t).

The yield had a gradual increase trend when MgO/Al₂O₃ ratio varied from 1.2 to 1.8. However, the yield of sinter dropped to 67.82 % when MgO/Al₂O₃ ratio was up to 2.2. This was the main reason for the increase of yield in that the MgO formed magnetite solid solution by solid state diffusion with increasing MgO/Al₂O₃ ratio. An endothermic process of magnetite mineralization reaction absorbed heat and prolonged the sintering time, resulting in a decrease of the vertical sintering speed. Moreover, sinter blends were expected to take a longer time to sinter due to the high viscosity of primary melts with high Al₂O₃ content. Thus, the holding time increased, the crystallization was sufficient and sinter structure became denser, resulting in an increased yield of sinter. The reduction of yield was attributed to the deterioration of sinter strength when the MgO/Al₂O₃ ratio was more than 1.8%. It led to the decrease of grain size and caused the decline of sinter yield. The sinter solid fuel consumption increased from 55.57 kg/t to 61.93 kg/t obviously when MgO/Al₂O₃ ratio changed from 1.2 to 2.2. The results indicated that the increase of MgO/Al₂O₃ ratio was not conducive to the decrease of solid fuel consumption.

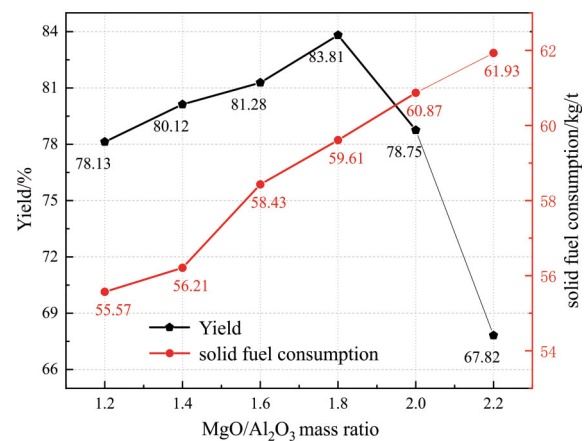


Figure 7. Influence of MgO/Al₂O₃ on sinter yield and solid fuel consumption

3.3 Influence on chemical composition of sinters

The chemical evolution of sinters in different MgO/Al₂O₃ ratio was tested, and the results are given in Table 4. As can be seen from Table 4, the content of TFe varies from 54.19% to 53.19%, while the FeO content showed an obvious increasing trend from 8.76% to 9.76% with increasing MgO/Al₂O₃ ratio. Silica and calcium oxide content remained stable, varying from 8.02% to 7.95% and 14.36% to 14.27%, respectively. The content of alumina changed slightly, and the content of magnesium oxide showed a continuous increasing trend.



Table 4. Chemical evolution of the sinters (mass percent, %)

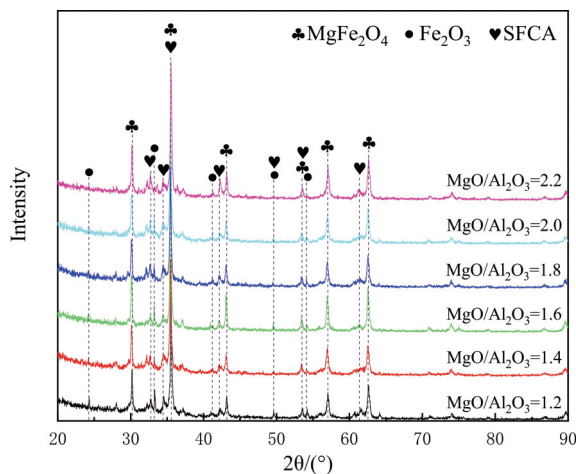
Samples	TFe	FeO	SiO ₂	CaO	Al ₂ O ₃	MgO
S1	54.19	8.76	8.02	14.36	2.18	2.61
S2	54.16	8.80	8.01	14.37	2.05	2.87
S3	54.03	8.89	7.96	14.30	1.97	3.15
S4	54.01	9.02	7.99	14.41	1.95	3.52
S5	53.92	9.13	7.98	14.29	1.89	3.77
S6	53.91	9.36	7.95	14.27	1.77	3.90

3.4 Influence on sinter mineral composition

The samples with different MgO/Al₂O₃ ratios were characterized by XRD to study the major existing phase in sinter, the results are shown in Figure 8. According to the XRD result, the main minerals in sinter were Fe₂O₃ (hematite), MgFe₂O₄, and SFCA (silico-ferrite of calcium and aluminum). Characteristic peak of SFCA phase became stronger, while the peak of Fe₂O₃ became weaker gradually when MgO/Al₂O₃ ratio increased from 1.2 to 1.6. The content of SFCA and Fe₂O₃ was reduced with further increasing of MgO/Al₂O₃ ratio, which was not conducive to the improvement of strength and reducibility of sinter. In addition, the formation of MgFe₂O₄ was promoted when MgO/Al₂O₃ ratio varied from 1.6 to 2.2. This is probably because the Mg²⁺ easily migrated into the magnetite lattice, occupying the vacancy of iron ion in the magnetite lattice and thereby forming MgFe₂O₄ [11].

3.5 Influence on sinter microstructure

The SEM-EDS results of the samples are shown in Figure 9, which displays the general microstructure of

**Figure 8.** Influence of MgO/Al₂O₃ on sinter mineral composition

sinter with different MgO/Al₂O₃ ratios. It can be observed that the variation of MgO/Al₂O₃ ratio did not change the main mineral types of sinter, which were hematite (spot 1), kirschsteinite (spot 2 and 7), magnetite (spot 3, 6, and 8), as well as silico-ferrite of calcium and aluminum (SFCA) (spot 4 and 5). It was found from Figure 9 (a-c) that the main mineral were skeletal hematite and porphyritic magnetite at low MgO/Al₂O₃ ratio. When MgO/Al₂O₃ ratio increased to 1.6, the form of hematite transformed from skeletal to porphyritic and granular, the proportion of acicular SFCA increased and the structural uniformity was improved. Magnetite and SFCA were obviously interweaved and corroded, whereas the formation of hematite was restrained when MgO/Al₂O₃ ratio was up to 1.8, which led to the reducibility of sinter reduce. With the further increase of MgO/Al₂O₃ ratio, the content of SFCA gradually decreased, which existed in the form of a plate. The content of plate-like magnetite increased significantly. Thus, sinter strength and reducibility were gradually reduced while low temperature reduction degradation performance improved when MgO/Al₂O₃ ratio was higher than 1.6.

3.6 Influence on metallurgical properties

Reducibility is a very important index to evaluate sinter performance, which depends on physical and chemical characteristics of the sinter. The physical characteristics include particle size and porosity while chemical characteristics include mineralogical composition and internal physical structure [6]. The porosity of six groups of sinters was measured using the Chinese standard of GB/T 10122, and the results are shown in Figure 10. The influence of MgO/Al₂O₃ ratio on reducibility characteristics is shown in Figure 11. It can be seen that the porosity of the samples S1-S5 increased primarily and then decreased with raising the MgO/Al₂O₃ ratio, and the change of reducibility of sinter was consistent with it. The porosity increased from 12.31% to 14.38% with changing MgO/Al₂O₃ ratio from 1.2 to 1.6, and the reduction increased from 82.57% to 88.54% correspondingly. The positive influence of MgO/Al₂O₃ ratio on the reducibility of sinter was due to the increase of porosity and the phases of hematite and SFCA. When MgO/Al₂O₃ ratio was beyond to 1.6, the reducibility started to reduce. During the reduction process the conversion of hematite into magnetite took place. The higher the amounts of magnetite in sinter, higher the FeO content and lower the reduction rate. It could be concluded that in order to improve sinter reducibility, the MgO/Al₂O₃ ratio should be less than 1.6.

The sinter RDI characteristics is important to maintain the furnace permeability and reduce the coke

consumption while increasing the productivity of the blast furnace [20]. During the low temperature reduction process of hematite phase to magnetite phase, volumetric change will accompany the phase

transformation and form a kind of inner stress. The inner stress will result in cracks in the sinter, which will cause the reduction degradation during the tumbling process of the sinter in blast furnace. The

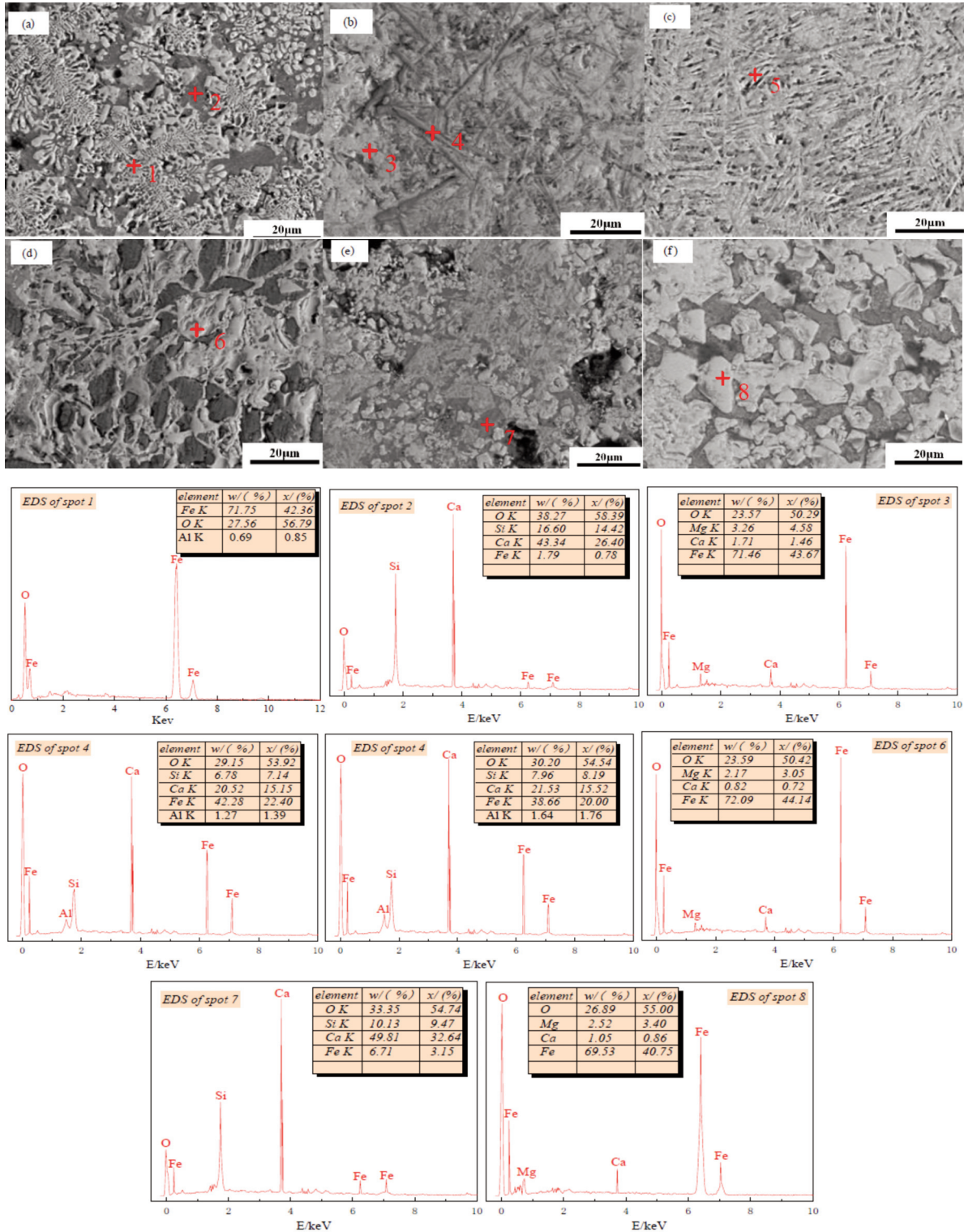


Figure 9. SEM-EDS results of sinters with different MgO/Al₂O₃ ratios; (a)1.2, (b)1.4, (c)1.6, (d)1.8, (e)2.0, (f)2.2



relationship between MgO/Al₂O₃ ratio and RDI of sinter is given in Figure 12. It is observed from the results that the RDI_{+3.15} of sinter rose from 84.72 % to 96.10 % while RDI_{-0.5} had the opposite trend with

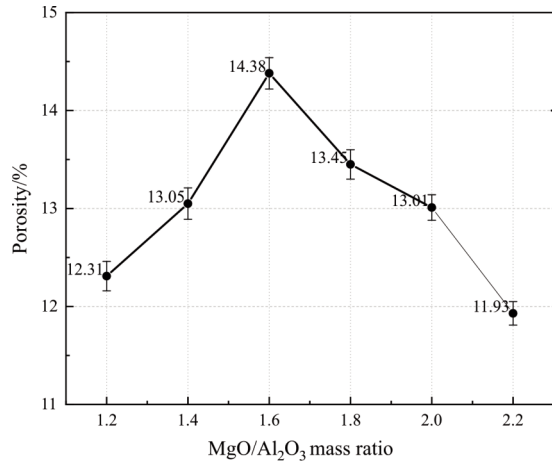


Figure 10. Effect of MgO/Al₂O₃ ratio on porosity of sinters

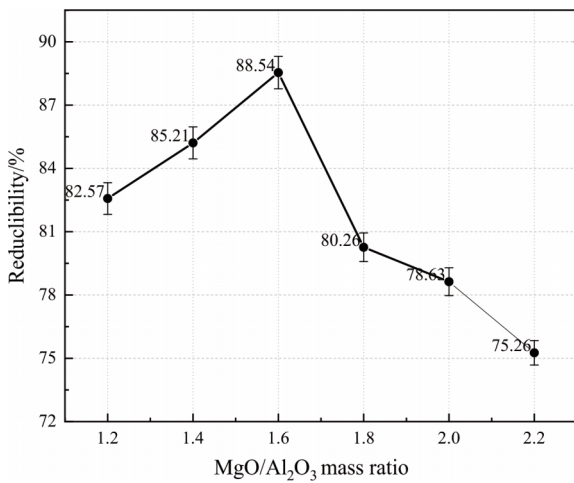


Figure 11. Effect of MgO/Al₂O₃ ratio on reducibility

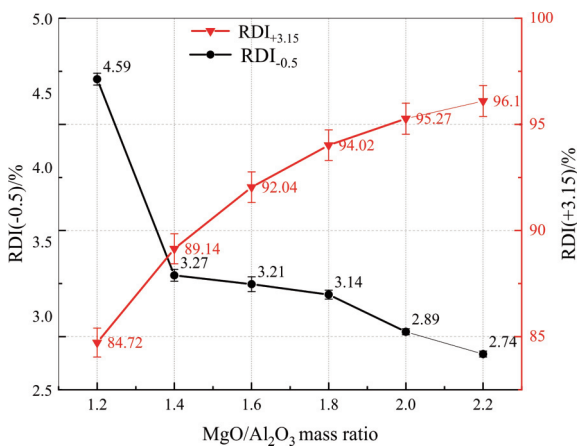


Figure 12. Effect of MgO/Al₂O₃ ratio on RDI

increasing MgO/Al₂O₃ ratio. The results demonstrate that MgO/Al₂O₃ ratio within the range of 1.2 to 2.2 was beneficial to the increase of RDI_{+3.15}. This is mainly because the formation of secondary hematite was restrained whereas magnetite content increased. Hence, less reduction taken place at lower temperature and led to less stress generated in the sinter matrix structure. Besides, MgO advanced the crystalline ability of the silicate melt and reduced the content of vitreous, which played a crucial role to strengthen the structure.

3.7 Mechanism analysis

More alumina dissolves into the hematite, SFCA and glass phase during sintering. The strength of these minerals will then decrease. As for the high alumina iron ore, it is expected to demand a high sintering temperature and a longer sintering time to promote melt formation and to produce a sinter with reasonable quality. As a result, the fuel rate increases and the sintering productivity reduces as the alumina content enhances. It is possible to improve the reactivity of alumina bearing materials and dilute the adverse effects of alumina by adding MgO content in the sinter blends. The schematic diagram of the influence of MgO/Al₂O₃ ratio on sinter is given in Figure 13. Most of the Mg²⁺ entered the magnetite lattice to form magnesiopinsels of the type (Fe·Mg) O·Fe₂O₃ by displacing Fe²⁺ ions from the magnetite lattice and a small amount was partitioned to glass and calcium silicate when MgO/Al₂O₃ ratio was low [21]. Thus, the hematite content in the sinter reduced and the solid solution reaction of alumina and hematite was weakened. At the same time, alumina reacted with magnesium oxide to form magnesia-alumina spinel. The alumina content in the solution of SFCA

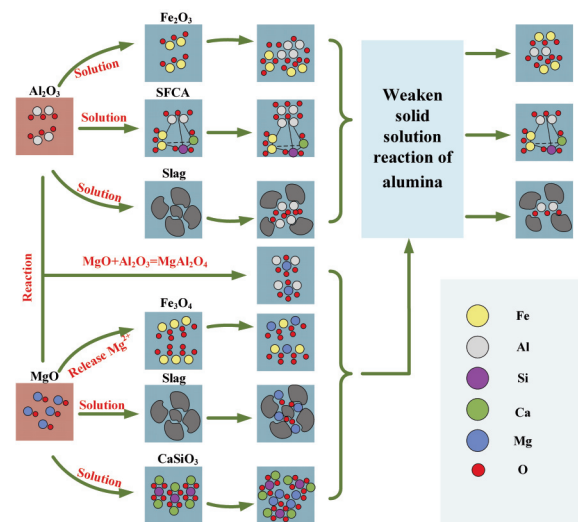


Figure 13. Influence mechanism of MgO/Al₂O₃ ratio on sinter



was reduced, and thus the strength of the SFCA improved. However, the FeO content in the sinter became higher, the hematite was greatly reduced, and the glass phase increased when MgO/Al₂O₃ ratio was over 1.8, which was not enough to eliminate the harm caused by alumina in sintering process. Thus, it made the sinter strength and reducibility worse.

In order to analyze the influence of MgO/Al₂O₃ ratio on the properties of sinter from the perspective of thermodynamics, the liquid-phase region projection of the CaO-SiO₂-Fe₂O₃-MgO-Al₂O₃ system was calculated by FactSage 7.1 at 1300°C when the MgO/Al₂O₃ ratio was 1.2, 1.4, 1.6, 1.8, and 2.2, respectively. As shown in Figure 14, it is clear that the liquidus was close to the iron-rich zone when the MgO/Al₂O₃ ratio was low. This indicates that sintering conditions could be improved when MgO/Al₂O₃ ratio was relatively low, which was conducive to the improvement of the sinter strength. However, the liquid phase region was obviously away from the iron-rich region and moved to the CaO and SiO₂-rich region when the MgO/Al₂O₃ ratio was over 1.8, and the amount of liquid phase was significantly reduced, resulting in deterioration of sinter strength.

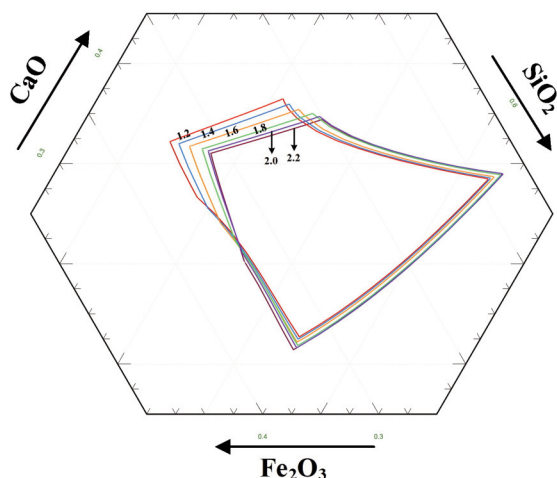


Figure 14. Liquid phase projection of CaO-SiO₂-Fe₂O₃-Al₂O₃-MgO system at different MgO/Al₂O₃ ratio

4. Conclusions

The effects of MgO/Al₂O₃ ratio on sinter performance, including strength, yield, solid fuel consumption, and FeO content, were investigated by the sintering pot test. XRD and SEM-EDS analysis were used to understand the change of sinter mineral composition and microstructure. The metallurgical properties of sinter were also tested. The following conclusions could be drawn from this study:

(1) Strength and yield improved at first then decreased owing to increasing MgO/Al₂O₃ ratio which was unfavorable for the formation of calcium

ferrites, but it increased the silicate phases. FeO content enhanced with increasing in MgO/Al₂O₃ ratio of sinter due to increase in magnetite phase. It was also not conducive to reducing fuel consumption with MgO/Al₂O₃ ratio that varied from 1.2 to 2.2.

(2) The main mineral composition of sinter developed from hematite to SFCA and the content of acicular SFCA increased when MgO/Al₂O₃ ratio changed from 1.2 to 1.6, and the sinter strength improved accordingly. The magnetite content increased significantly and the hematite content gradually decreased when MgO/Al₂O₃ ratio was higher than 1.6, and the reducibility decreased.

(3) With MgO/Al₂O₃ ratio increasing in the sinter, RI firstly improved and then it was reduced. The RDI_{+3,15} of sinter became better by stabilizing the cation vacancies in the structure of magnetite and decreased the content of hematite resulting in that less reduction took place at lower temperature.

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References

- [1] F. Kongoli, I. McBow, R. Budd, S. Llubani, A. Yazawa, J. Min. Metall. Sect. B-Metall., 46 (2) B (2010) 123-130.
- [2] C. Y. Ding, X. W. Lv, S. W. Xuan, K. Tang, C. G. Bai, ISIJ Int., 56 (12) (2016) 2118-2125.
- [3] N. Yang, X. M. Guo, N. Saito, K. Nakashima, J. T. Zhao, ISIJ Int., 58 (8) (2018) 1406-1412.
- [4] H. S. Han, F. M. Shen, X. Jiang, C. G. Bi, H. Y. Zheng, Q. J. Gao, J. Iron Steel Res. Int., 26 (11) (2019) 1171-1177.
- [5] T. J. Chun, G. T. Mu, Q. M. Meng, H. M. Long, P. Wang, C. G. Bi, J. Min. Metall. Sect. B-Metall., 55 (2) (2019) 167-175.
- [6] T. Umadevi, K. Nelson, P. C. Mahapatra, M. Prabhu, M. Ranjan, Ironmak. Steelmak., 36 (7) (2009) 515-520.
- [7] M. Sinha, S. H. Nistala, S. Chandra, T. R. Mankhand, A. K. Ghose, Ironmak. Steelmak., 44 (2) (2017) 100-107.
- [8] A. Shankar, M. Görnerup, S. Seetharaman, A. K. Lahiri, Metall. Mater. Trans. B, 37 (6) (2006) 941-947.
- [9] M. Zhou, S. T. Yang, T. Jiang, X. X. Xue, Ironmak. Steelmak., 42 (3) (2015) 217-225.
- [10] X. D. Xing, Z. G. Pang, C. Mo, S. Wang, J. T. Ju, J. Non-Cryst. Solids, 530 (2020) 119801.
- [11] F. Pan, Q. S. Zhu, Z. Du, H. Y. Sun, ISIJ Int., 58 (4) (2018) 652-659.
- [12] X. D. Xing, S. Wang, Q. L. Zhang, J. Chem., (2019).
- [13] K. Higuchi, M. Naito, M. Nakano, Y. Takamoto, ISIJ Int., 44 (12) (2004) 2057-2066.
- [14] L. H. Hsieh, ISIJ Int., 45 (4) (2005) 551-559.



- [15] J. J. Dong, G. Wang, Y. G. Gong, Q. G. Xue, J. S. Wang, Ironmak. Steelmak., 42 (1) (2015) 34-40.
- [16] Z. Wang, J. L. Zhang, H. B. Zuo, R. B. Wang, K. C. Sintering and Pelletizing, 38 (2013) 1-5 (in Chinese).
- [17] L. H. Zhang, S. T. Yang, W. D. Tang, H. Yang, X. X. Xue, Ironmak. Steelmak., 47 (7) (2019) 821-827.
- [18] T. Umadevi, A. K. Roy, P. C. Mahapatra, M. Prabhu, M. Ranjan, Steel Res. Int., 80 (11) (2009) 800-807.
- [19] T. Umadevi, R. Sah, P. C. Mahapatra, Miner. Process. Extr. Metall., 123 (2) (2014) 75-85.
- [20] T. Umadevi, A. V. Deodar, P. C. Mahapatra, M. Prabhu, M. Ranjan, Steel Res. Int., 80 (9) (2009) 686-692.
- [21] L. H. Zhang, S. T. Yang, W. D. Tang, X. X. Xue, Minerals, 9 (5) (2019) 324-337.

UTICAJ VISOKOG ODNOSA MgO/Al_2O_3 (1,2 DO 2,2) NA PONAŠANJE PRILIKOM SINTEROVANJA I NA METALURŠKE OSOBINE

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Apstrakt

Da bi se ispitalo uticaj odnosa MgO/Al_2O_3 u rasponu od 1,2 do 2,2 na ponašanje rude železa prilikom postupka sinterovanja izvršen je test u posudi za sinterovanje. Za karakterizaciju su korišćene metode rentgenske difrakcije (XRD), skenirajući elektronski mikroskop (SEM) i energijsko disperzivna spektroskopija (ESD). Rezultati su pokazali da su se čvrstoća, prinos i reduktibilnost tokom sinterovanja u početku povećavale, a da su se zatim smanjivale kada se odnos MgO/Al_2O_3 povećao sa 1,2 na 2,2. Indeks je imao najveću vrednost kada je čvrstoća bila na 70,6%, prinos 83,81%, a MgO/Al_2O_3 odnos 1,8. Indeks redukcije je imao najveću vrednost od 88,54% kada je MgO/Al_2O_3 odnos bio 1,6. Sadržaj FeO, potrošnja čvrstog goriva i $RDI_{+3.15}$ su se povećali značajno prilikom sinterovanja kada se odnos MgO/Al_2O_3 povećao. Kada je odnos MgO/Al_2O_3 bio 2,2 postrošnja čvrstog goriva i $RDI_{+3.15}$ su dostigli maksimalne vrednosti od 61,93 kg/t i 96,1 %, respektivno. Modifikacija SFCA je imala igličast oblik kada je odnos MgO/Al_2O_3 bio manji od 1,6, a zatim je dobila pločasti oblik i sadržaj se takođe smanjio. Sadržaj magnetita se povećavao, dok se sadržaj hematita smanjivao kako se odnos MgO/Al_2O_3 povećavao.

Ključne reči: Odnos MgO/Al_2O_3 ; Sinterovanje; Čvrstoća; Metalurške osobine

