http://dx.doi.org/10.4322/tmm.2014.051

STUDY ON SOFTENING AND DROPPING PROPERTIES OF METALIZED BURDEN INSIDE BLAST FURNACE

Bi-yang Tuo [1,2]
Sheng-li Wu [1]
Li-hua Zhang [1]
Jian-long Wu [1]
Ying Sun [1]

Abstract

The inferences of burden metallization rate on softening-melting dropping properties were investigated through softening-melting dropping test of three kinds of metalized burden pressure drop. The results indicated that the softening-melting temperature interval of pre-reduction mixed burden is bigger than primeval mixed burden, the melting interval narrow with the rise of metallization rate of ferric burden as well as dropping temperature interval. The average pressure drop, maximum pressure drop and softening-melting dropping properties eigenvalue decrease with the rise of metallization rate of ferric burden. Besides, the dropping temperature of burden reduces with the rise of carbon content of molten iron. The combination high metalized burden and higher carbon content of molten iron is benefit to decreasing thickness of cohesive zone and improve permeability of cohesive zone.
Keywords: Iron-bearing burden; Metallization rate; Softening-melting dropping properties; Blast furnace.

1 INTRODUCTION

In order to meet the need of the global "low carbon economy", energy savings and pollutant reductions on blast furnace ironmaking process is becoming a strategic problem to be solved in iron and steel industry. Softening-melting dropping property (SDP) of iron-bearing burden has great effect on blast furnace operation [1] such as smooth operation, productivity, fuel consumption and molten iron components and so on.

Excellent softening melting dropping property of iron-bearing burden inside blast furnace is an important index in ironmaking research. Although lots of works such as the influences of iron-bearing burden proportion, Fe content, MgO content and binary basicity on SDP have been studied before [2-6], few work focused on the effect of metallization rate on SDP.

Besides, it is possible to use some metalized burden in blast furnace with implement of sponge iron production process with rotary hearth furnace [7-9]. Study shows that the innovation process based on ore-coke coupling reaction is expected to increase metallization degree of burden [10,11]. The influence of these metalized burdens on SDP is becoming the hot spot in ironmaking research.

In order to investigate and master the varied law of SDP, experiments are conducted about different degrees of metalized burden. Relationships between SDP and correlative factors i.e. metallization rate and carbon concentration of the iron-bearing burden, carburizing rate, carbon content in hot metal are deeply studied in this paper.

2 MATERIAL AND METHODS

Experiments have been conducted on the softening--melting dropping properties of unreduced ferric burden A and pre-reduced burden B, C, and the T_s, T_m, T_d, shrinkage characteristic, pressure drop and SMD difference of them are compared.

The composition of ferric burden is listed in Table 1. Ferric burden B and C are pre-reduced burden which are made from ferric burden A of 200 g reduced to metallization rate of 45% and 75% respectively. The grain size of ferric burden is 10~12.5mm, the grain size of the experiment coke from Baosteel is 6.3~10 mm.

A measuring device for high temperature properties was shown in Figure 1. The burden was charged into the graphite reaction tube (inner diameter 48 mm, length 270 mm). A sample having a layer thickness of 65 mm was charged in a crucible and a layer thickness of 20 mm was placed over and below that.

Experimental conditions are shown in Table 2. Heating up rate is 10°C/min below 900°C and 5°C/min from 900°C to end, and then each experiment is finished. Gas flow is 5 L/min of N_2 below 900°C and the flow rate of reducing gas is 12L/min from 900°C to end. And composition of the reducing gas is CO:N_2 = 70:30 (%). The burden load was 1 kg/cm^2, Behavior of softening and shrinking was evaluated through measuring variations in layer thickness

[1]State Key Laboratory of Advanced Metallurgy, University of Science and Technology Beijing, Beijing 100083, China. E-mails: yntby@163.com; wu_shengli@263.net; zhanglh@metall.ustb.edu.cn; jianlong231@163.com; mec.bytuo.gzu.edu.cn
[2]College of Mining, Guizhou University, Guiyang 550025, China

Table 1. Ferric burden properties /%

Burden	Metallization rate	FeO	C	Sinter	Pellet	Lump ore
A	0	5.55	0	65.7	19.8	14.5
B	45	51.21	0.10	65.7	19.8	14.5
C	78	24.82	1.10	65.7	19.8	14.5

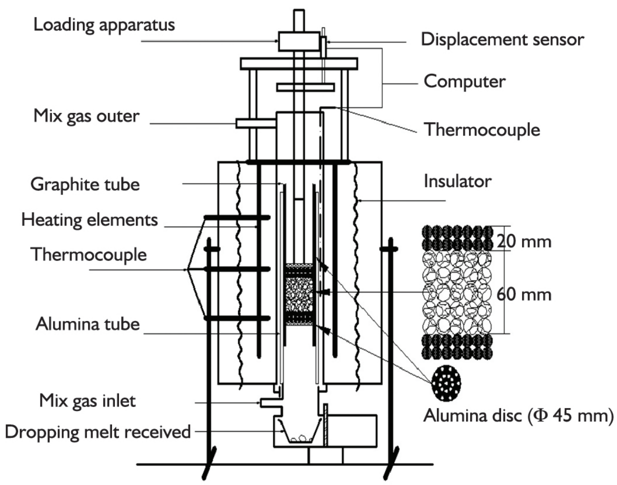

Figure 1. Schematic diagram of softening-melting dropping experimental apparatus and charging.

Table 2. Melting and dropping experiment condition of ferric burden

Ferric burden	before 900°C			after 900°C			
	N_2	Gas flow	Hearting rate	N_2	CO	Gas flow	Heating rate
	%	L/min	°C/min	%	%	L/min	°C/min
A							
B	100	5	10	70	30	12	5
C							

and pressure drop. The temperature and layer thickness was measured by thermocouple and displacement sensor respectively. The pressure drop between gas inlet and gas outer was measured by U tube manometer. Carbon content of molten iron (C_{Pig}) was analysed by chemical analysis. Experiment was finished once the molten iron dropped. The experiment data such as temperature, column thickness and pressure are all real time recorded in the computer.

3 RESULTS

The process parameters of ferric burden under softening-melting dropping are shown in Table 3. Results of the softening-melting dropping experiments of ferric burden A, B and C are shown in Figures 2-4 and Tables 4. The softening-melting dropping zone can be divided into three zones, namely softening-melting zone, melting zone and dropping zone in order to study the influence of ferric burden metallization rate on the softening-melting dropping properties. Based on the above research, the ferric burden softening-melting property eigenvalue (SMD_1), the melting property eigenvalue (SMD_2), the dropping property eigenvalue (SMD_3) and the softening-melting dropping properties eigenvalue, are further studied.

Table 3. Process parameters of ferric burden under softening-melting dropping

Symbol	Meaning	Unit
T_s	Temperature when bed shrinkage rate increase obviously or unit bed pressure drop markedly elevated and this temperature where the charge column height shrinkage is about 10%	°C
T_m	Temperature at which the pressure drop or unit pressure drop start steeply rise at the moment	°C
T_{Pmax}	Temperature of unit bed maximal pressure drop	°C
T_d	Temperature when molten iron begin to drop	°C
T_1	Softening-melting temperature interval ($T_1 = T_m - T_s$)	°C
T_2	Melting temperature interval ($T_2 = T_{Pmax} - T_m$)	°C
T_3	Dropping temperature interval ($T_3 = T_d - T_{Pmax}$)	°C
$T_{1\sim3}$	Softening-melting dropping temperature interval ($T_{1\sim3} = T_d - T_s$)	°C
S_1	Shrinkage value of burden column height in softening-melting temperature interval	%
S_2	Shrinkage value of burden column height in melting temperature interval	%
S_3	Shrinkage value of burden column height in dropping temperature interval	%
C_{Pig}	Carbon content of molten iron	%

4 DISCUSSION

4.1 Variation of Charge Column Height

4.1.1 Softening-melting temperature interval

Experiment results are shown in Figures 2-5. The order of T_s is: A>C>B. As for T_m, the order is: B>C>A. And the order of T_1 is: B>C>A.

The reduction process of ferric burden A is $Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe$, and that of burden B and C is $FeO \rightarrow Fe$. Reductions of $Fe_2O_3 \rightarrow Fe_3O_4$ and $Fe_3O_4 \rightarrow FeO$ need some time to finish, which results that the charge column of burden A needs a longer time to reach T_s and T_s of burden A has exceeded that of ferric burden B and C. FeO contents in ferric burden B and C are respectively 51.21% and 24.82% at the beginning of reduction of 900°C, which begin to decrease as the reduction goes on. Therefore T_s of ferric burden B is lower than that of burden C.

The main reason why T_m of burden A is higher than that of burden B, is that the metallization rate of burden B is 45% at the beginning of reduction and the metallization rate becomes higher with the reduction, and the whole ferric burden B is almost reduced to spongy iron which is difficult to produce low melting point mineral. The main reason T_m of burden B is higher than that of burden C is

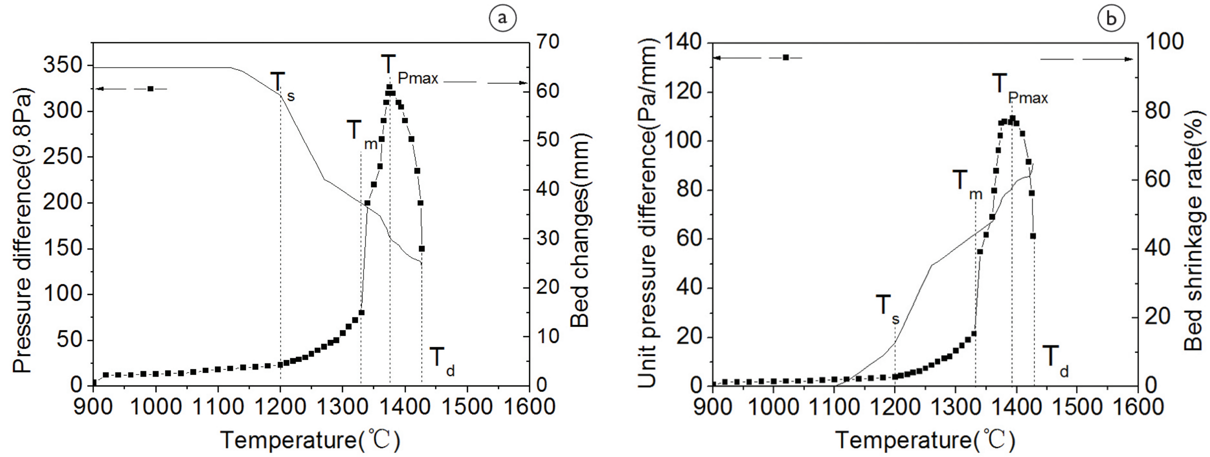

Figure 2. The experimental results of ferric burden A.

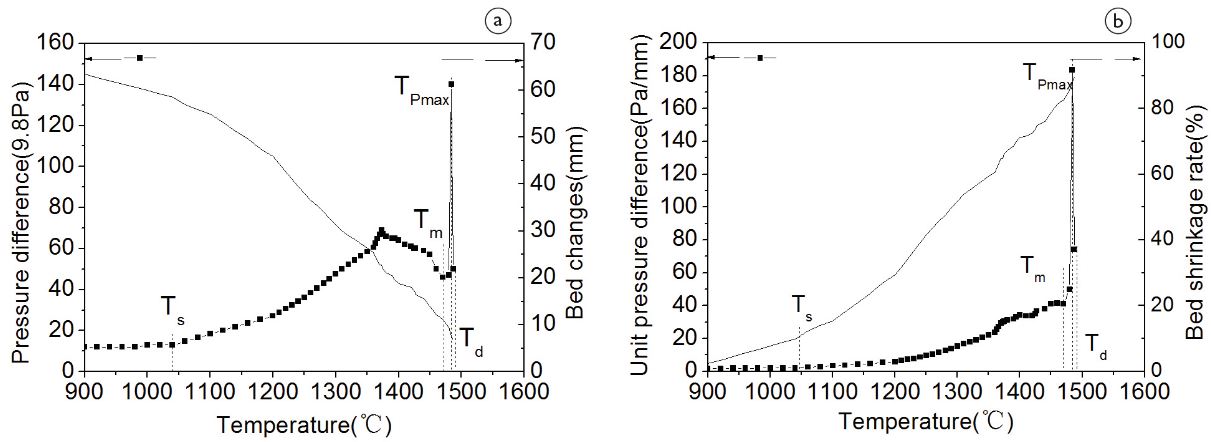

Figure 3. The experimental results of ferric burden B.

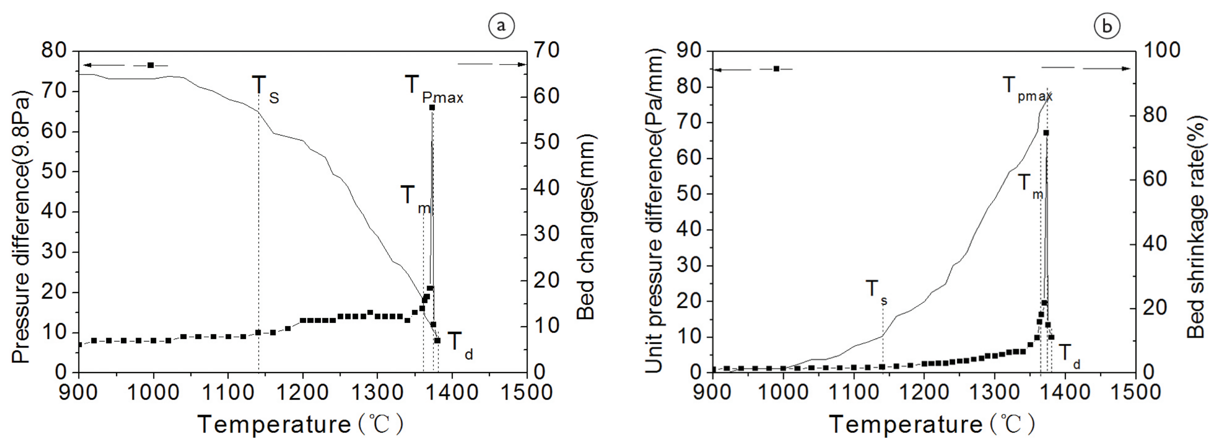

Figure 4. The experimental results of ferric burden C.

that all of ferric burden B and C are almost reduced to iron and the liquid appearance temperature of charge burden decreases as carbon content of burden increases according to blue lines in the Fe-C diagram in Figure 6. Therefore, the carbon content of ferric burden C is higher than that of burden B.

Table 4 shows that in the softening melting temperature range, the shrinkage value (S_l) of charge column B is the minimum and that of burden A is the next and that of burden C is the maximum. The main reason is analyzed as following. Compared with ferric burden B, T_s of burden A is higher, and T_l is narrower, the liquid formation rate is relatively fast, thus the shrinkage rate is smaller.

While T_l of burden B is wider, and the softening--melting shrinkage is slower, and S_l corresponding to T_m is relatively large, therefore softening-melting process is more

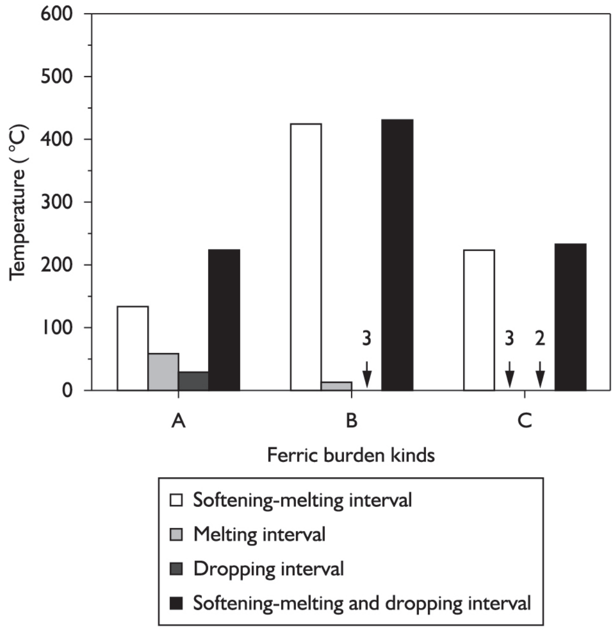

Figure 5. Effect of different metallic ferric burden on its softening-melting dropping interval.

completed. Compared with ferric burden B, T_m of ferric burden C is rather low, but S_1 is relatively large.

4.1.2 Melting temperature interval

Melting temperature interval (T_2) of ferric burden is defined as difference values between melting starting temperature (T_m) of charging column and melting ending temperature (T_{Pmax}). The value reflects the high temperature melting properties of ferric burden to some extent. T_2 of ferric burden A is the maximum, and burden B is the next, and burden C is the minimum, which is presented in Table 4 and Table 5. Obviously, burden metallization rate is larger, the narrower T_2.

Compared with ferric burden A, T_{Pmax} of burden B is much higher. The main reason is that T_{Pmax} of ferric burden increases with rising metallization rate and decreases with rising FeO content in charging column. T_{Pmax} of burden C is the lowest among ferric burden A, B and C. The main reason is higher carbon content in ferric burden C at the melting process, which can be verified by the blue lines in Fe-C diagram in Figures 6, in addition, it can be verified

Table 4. Temperature interval parameters and shrinkage range of burden

Burden	C_{Pig}	Ts	Tm	T_{Pmax}	T_d	T_1	T_2	T_3	$T_{1\sim3}$	S_1	S_2	S_3
	%	°C									%	
A	3.16	1200	1335	1394	1425	135	59	31	225	31	15	6
B	2.95	1045	1470	1484	1487	425	14	3	442	28	5	2
C	3.93	1146	1370	1373	1375	224	3	2	229	36	2	1

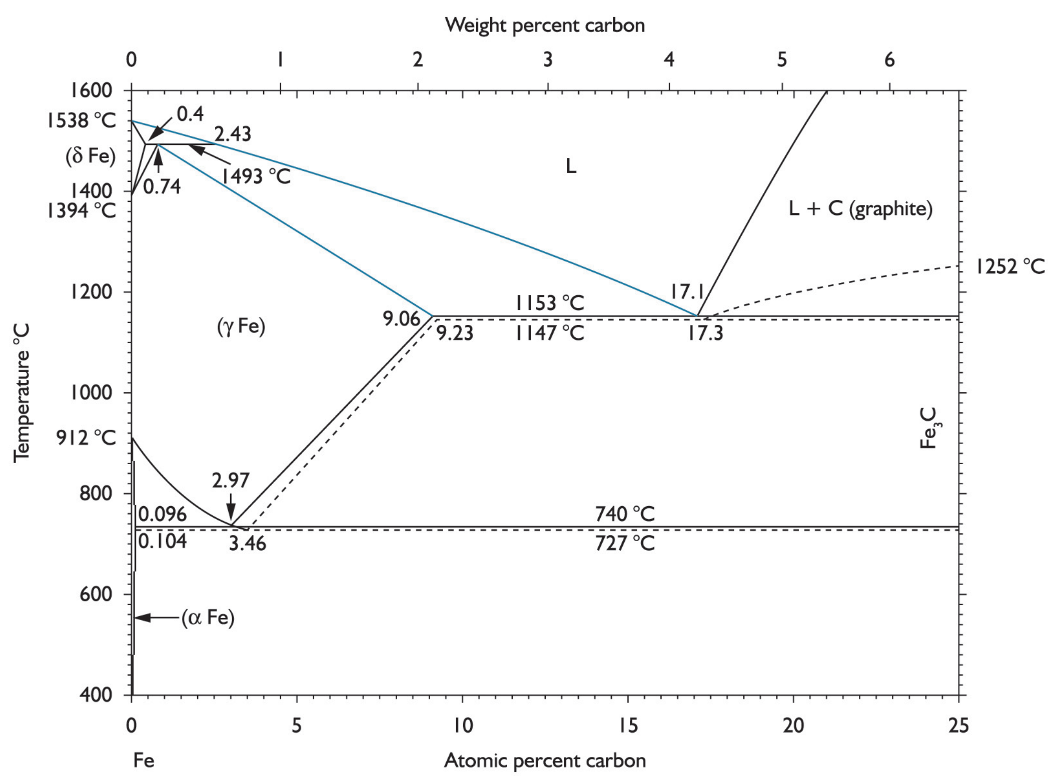

Figure 6. Fe-C diagram.

Table 5. Pressure drop and property eigenvalues of ferric burden

Burden	Pav_1	Pav_2	Pav_3	Pav	SMD_1	SMD_2	SMD_3	SMD
	Pa				kPa·°C			
A	440	2530	2590	1342	57	162	85	304
B	390	599	950	393	167	8	3	178
C	141	435	390	148	24	1.3	0.8	26.1

by means of Figure 7. Therefore, T_{Pmax} of ferric burden is mainly determined by metallization rate of charging burden and carbon content, and the higher carbon content is at the same metallization rate condition, the lower T_{Pmax} becomes.

As can be seen from Table 4, the charge column shrinkage value (S_2) of ferric burden A, B and C in melting temperature range are 15%, 5% and 2% respectively. The T_2 of burden B and C is rather narrow in comparison with burden A. The reason is that the liquid content of burden B and C increase rapidly to the maximum, and the sharp increasing interval of liquid content is rather narrow. T_2 of ferric burden C is narrower than burden B, which because that the metallization rate of burden C is larger than that of burden B. Therefore, in melting temperature interval, the S_2 decreased with the rise of metallization rate, and the higher the burden metallization rate is, and the lower the increased value of shrinkage rate is.

4.1.3 Dropping temperature interval

The dropping temperatures (T_d) of ferric burden A, B and C are 1,425°C, 1,487°C and 1,375°C respectively, and the dropping temperature ranges are 31°C, 3°C and 2°C, which is illustrated in Table 4 and Table 5. T_d of ferric burden mainly depends on the carbon content in molten iron and Figure 6 and Figure 7 indicate that T_d of molten iron is related with the carbon content (C_{Pig}) in molten iron, which shows that the higher C_{Pig} is, the lower T_d becomes. T_3 of burden A, B and C reduces in turn, which is mainly because of the rise of burden metallization rate leading to the narrowing of dropping temperature interval. The high metallization rate of ferric burden C causes T_3 only 2-3°C, which pressure drop reduce immediately after burden melted. So T_d of burden decreases with the increase of C_{Pig}, and T_3 narrows with the rise of the metallization rate. As can be seen from Figure 7, the carburized amount of burden in experimental furnace is less related to metallization rate and carbon content of raw material, and C_{Pig} is directly correlated to the carbon content of the ferric burden before charging into experimental furnace.

In dropping temperature interval, the charge column shrinkage value (S_3) of ferric burden A, B and C are 6%, 2% and 1% respectively, which is listed in Table 4. The higher the metallization rate is, the smaller the corresponding S_3 value in dropping temperature range is. The main reason is that all of ferric burden has melted into liquid in dropping temperature interval, and the thickness of charging column

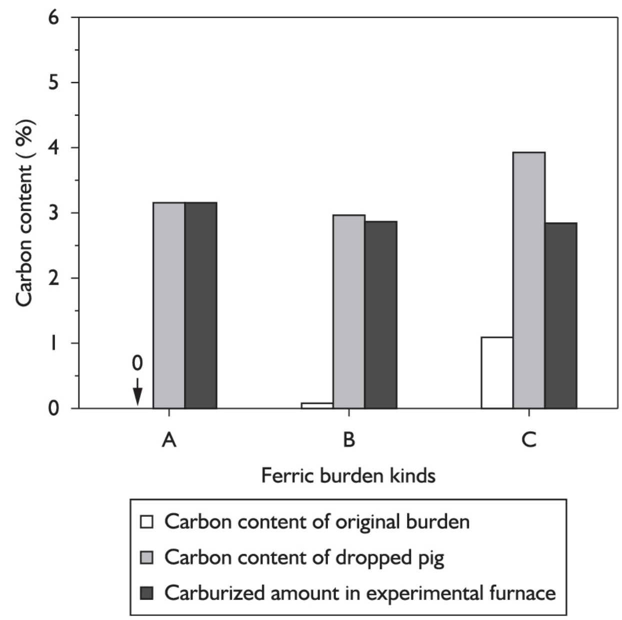

Figure 7. Carburizing rate of ferric burden inside the experimental stove.

is minimum, which leads to charging column not shrink again in theory, while there is a little change actually, and this is mainly attribute to the decrease of surface viscosity of liquid making the surface liquid drop into coke layer. The molten slag and iron viscosity of burden A is rather high and the no-dropping temperature interval is much wider than burden B. While the molten slag and iron viscosity of burden B and C is rather low, the no-dropping temperature interval of which is much narrow and the interval value is only 2-3°C. And the slag and molten iron residence time in dropping temperature interval becomes short with the rise of the metallization rate. Therefore, the high metallization rate burden is beneficial to decrease the molten slag and iron viscosity and the width of dropping temperature interval.

In conclusion, the T_1 and $T_{1\sim3}$ of burden A are narrower than that of burden B and C. And T_2 and T_3 of burden A, B and C becomes narrow with the increase of metallization rate. The charging column shrinkage value of burden B and C is much larger than burden A. Considering T_1 alone, it seems that the softening-melting dropping properties of unreduced ferric burden is better than metalized burden. However whether wider T_1 indicate bad soften-melting dropping properties needs to be studied further. The discussion of the influence of metallization rate of ferric burden on charging column pressure drop is shown as following.

4.2 Pressure Drop Changes of Charge Column

Pressure drop of the cohesive zone is the maximum in blast furnace. It is about 60% of the total pressure drop, and it determines the stable of blast furnace smelting operation [12]. It is important to study the influence of metallization rate of ferric burden on the pressure differential in softening-melting dropping process.

As can be seen from Figures 2, 3 and 4, with rising charging column temperature, the charging column pressure drop of burden A increases rapidly to maximum and then decreases slowly and at this moment the molten iron starts dropping. Charging column pressure drop of burden B firstly increases slowly to a higher point, then increases sharply to the maximum, at this moment the molten iron starts dropping. While pressure drop of burden C increases steeply and then decreases immediately before the molten iron drops. In the softening -melting interval, the unit pressure drop of burden A, B and C increase slowly, and when the charging column temperature reaches to melting starting temperature, the unit pressure drop sharply increases to maximum for the decrease of lacuna in charging column caused by the rapidly melting of burden, which is listed in Figures 3, 5 and 7. Melting terminates at the moment, but the molten iron will not drop immediately for higher viscosity.

Seen from charging column permeability in softening-melting temperature interval, the unit charging column pressure drop of burden A, B and C increase slowly. As can be seen from Table 5 and Figure 8, both the average pressure drop (P_{av1}) and maximum pressure drop decrease with increasing metallization rate, thus the charging column permeability of burden A is the worst, that of burden B is better, and that of burden C is the best. Therefore, the charging column permeability is improved with the rise of the metallization rate in softening melting temperature interval.

As for the charging column permeability in melting temperature interval, the unit charging column pressure drop of burden A, B and C all increase rapidly to maximum, which are listed in Table 5. As can be seen from Figure 8, both the average pressure drop (P_{av2}) and maximum pressure drop decrease with the rise of metallization rate in melting temperature interval, it again shows that the higher the metallization rate is, the better the charging column permeability is.

The variation of charging column permeability in the dropping temperature interval is presented in Figures 2, 3 and 4. In general, the charging column pressure drop reduces gradually or sharply in dropping temperature interval. As is shown in Table 5, the maximum pressure drop and average pressure drop (P_{av3}) of ferric burden decrease with the rise of metallization rate in dropping temperature interval.

Above analysis illustrates that the charging column pressure drop is mainly related to the liquid phase volume of slag and iron and the melting condition of iron metal. The reduction process of burden A is much long, and the FeO content increases to the maximum and then decreases slowly with the rise of temperature. So the higher pressure drop range of burden A is rather large.

While the average pressure drop (P_{av}) and maximum pressure drop (P_{max}) of burden B and C are small in softening-melting dropping interval, and maximum pressure drop

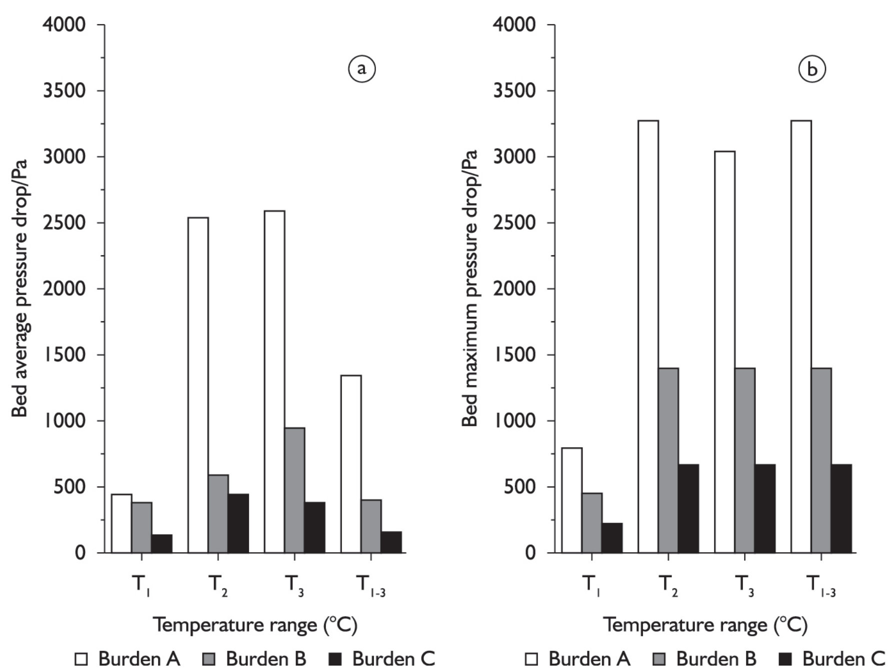

Figure 8. Charging column pressure drop of burden A, B and C.

interval is narrow, it indicates that the iron in charge column of pre-reduced burden melts rapidly at a certain temperature, then penetrates into the coke passages, and drop in a flash. This causes the peak value interval of maximum pressure is only 2-3°C. So the higher the metallization of ferric burden is, the better the permeability of charge column is.

4.3 Softening-melting Dropping Property Eigenvalue of Ferric Burden

The charge column lacuna of ferric burden gradually decreases to disappear from softening-melting starting temperature to dropping temperature. The charging column shrinkage in softening-melting, melting and dropping temperature interval all affect the burden smelting. Evaluating exactly softening-melting, melting, and dropping properties makes an important significance on blast furnace ironmaking.

The softening-melting dropping property eigenvalue is defined as the sum of the temperature integral of pressure drop function in softening-melting, melting and dropping temperature interval. In order to calculate conveniently, the calculation with infinitesimal method for pressure drop function needs to be fitted with the experiment data [13]. Each interval SMD is calculated by formula 1.

$$SMD = \int_{T_s}^{T_d} P(T)dT = SMD_1 + SMD_2 + SMD_3 = \int_{T_s}^{T_m} P(T)dT + \int_{T_m}^{T_{Pmax}} P(T)dT + \int_{T_{Pmax}}^{T_d} P(T)dT = \frac{1}{2}\sum_{i=1}^{n}(P_{i+1} + P_i) \times (T_{i+1} - T_i) \quad (1)$$

This formula indicates that SMD is the integral of pressure drop to temperature from T_s to T_d range. Each temperature interval indicates the width of T_1, T_2 and T_3. The integral of pressure drop to temperature of each temperature interval is defined as softening-melting property eigenvalue (SMD_1), the melting property eigenvalue (SMD_2) and dropping property eigenvalue (SMD_3), which are shown in Table 5. T_i is arbitrary temperature value from T_s to T_d. P_i is the corresponding pressure drop value of temperature T_i. The formula is helpful to further understanding about the width of T_1, T_2 and T_3 of each ferric burden, and the pressure drop variance of charging column and the property eigenvalue are also characterized by it. To use the formula 1 is beneficial to correctly evaluate the SMD of ferric burden. By formula 1 known, in the same temperature interval, the smaller the eigenvalue of SMD is, the better the permeability of cohesive zone becomes in blast furnace.

The SMD calculated by formula 1 is shown in Table 5 and Figure 9. The SMD_1 of burden B is the maximum, SMD_1 of burden A is the next and SMD_1 of burden C is the minimum.

The Fe_2O_3 in burden A is gradually reduced to FeO, and part of FeO is also reduced to Fe with rising temperature. FeO would not affect the charging column permeability until FeO content is accumulated to a certain

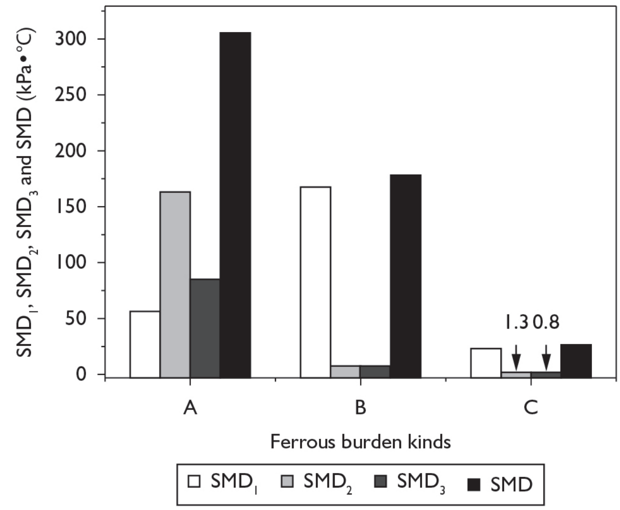

Figure 9. Softening-melting dropping property eigenvalues of burden A, B and C.

level in a higher temperature. Compared with burden A, the FeO content of burden B is the maximum and the value is 51.21% when burden B begin to be reduced at 900°C, which produces much of low melting temperature substance. Lacuna of charging column reduces, and pressure drop rises, and the permeability becomes worse for the softening-melting of low melting temperature substance. In addition, T_s of burden B becomes lower, and T_1 becomes wider because of the maximum FeO content at the beginning of reduction. Therefore, SMD_1 of burden A is larger than that of burden B in softening-melting temperature interval. While the FeO content in burden C is much smaller at the beginning of reduction, FeO gradually reduces to Fe with rising temperature. This leads to lower amounts of the low melting temperature substance produced by FeO and oxides in gangue minerals, which has little influence on the permeability of charging column, so the charging column pressure drop of burden C is rather low and the permeability is the best.

As can be seen from Table 5 and Figure 9, the SMD_2 of ferric burden A is the maximum, followed by that of burden B and that of burden C is minimum. The maximum SMD_2 of burden A is caused by wider T_2 and higher pressure drop of the charging column, which can be verified in Figure 2 and Figure 3. While the maximum liquid volume of burden A in melting temperature interval causes the pressure drop of charging column larger. The SMD_2 of burden B and C is 8k Pa·°C and 1.3k Pa·°C respectively. This indicates that burden B and C are almost turned into Fe, which makes the temperature interval rather narrow and pressure drop much low. In conclusion, SMD_2 of ferric burden decreases with increasing metallization rate.

SMD_3 of ferric burden A is the maximum, burden B is the next and burden C is the minimum, according to Table 5 and Figure 9 The main reason is that the viscosity of melting slag and iron of burden A is much high in the dropping temperature interval, the no-dropping temperature interval of melting slag and iron is much wider, that is the duration of the higher pressure drop is rather long. While SMD_3 of burden B and C is much small, because that the much low viscosity of melting slag and iron of high metallization rate cause it to drop immediately after melted and layered, which results in the narrow dropping temperature interval.

The softening-melting dropping interval, $T_{1\sim3}$, of burden A, B and C is 225°C, 432°C and 229°C, while the average pressure drop(P_{av}) of burden is 1,342Pa, 393Pa and 148Pa respectively. SMD of ferric burden decreases with the rise of the metallization rate. In conclusion, the softening--melting dropping properties of ferric burden cannot be evaluated only by softening melting dropping temperature range, because the pressure drop is more important than the temperature range. Therefore the softening-melting dropping properties ought to be evaluated by real time differential pressure combined with temperature range.

5 CONCLUSIONS

- With the rise of metallization rate of ferric burden, the softening-melting starting temperature decreases, the softening-melting temperature interval becomes wide, but the total pressure drop of softening-melting layer obviously decreases and permeability is improved.
- When the metallization rate of ferric burden is improved, the pressure drop steep rising temperature pressure dropincreases, the melting temperature interval becomes narrow, and the pressure drop of charge column decrease, the permeability is improved.
- Compared with unreduced burden A, the carburization reaction of metalized burden becomes weak, and the dropping temperature increases with the decreases of carbon content of metalized burden. The carbon content of molten iron increases with rising carbon content of metalized burden that resulting in decreasing dropping temperature of burden.
- The combination of high metalized burden and higher carbon content of molten iron can decrease the liquid volume of charging column in high temperature, improve the softening-melting dropping properties of ferric burden and decrease the pressure drop of cohesive zone, and improve the permeability.

Acknowledgements

The financial support of the National Natural Science Foundation of China (50974143), and Fundamental Research Funds for the Central Universities (FRF-TP-12-021A) is gratefully acknowledged.

REFERENCES

1 Yutaka U, Kaoru N, Yoshinor M, Kohei S, Shusaku K, Takaiku Y. Subjects for achievement of Blast Furnace operation with low reducing agent rate. ISIJ International. 2005;45(10):1379-1385. http://dx.doi.org/10.2355/isijinternational.45.1379.

2 Chin EL, Leanne TM, Damiea PO. Lump ore and sinter behaviour during softening and melting. ISIJ International. 2011;51(6):930-938. http://dx.doi.org/10.2355/isijinternational.51.930.

3 Wu SL, Han HL, Xu HF, Wang H, Liu X. Increasing lump ores proportion in Blast Furnace based on the high-temperature Interactivity of Iron bearing materials. ISIJ International. 2010;50(5):686-694. http://dx.doi.org/10.2355/isijinternational.50.686.

4 Kohei S, Kaoru N, Masahiko H, Takanobu I, Shusaku K, Takaiku Y. Effect of high Al2O3 slag on the Blast Furnace operations. ISIJ International. 2008;48(4):420-429. http://dx.doi.org/10.2355/isijinternational.48.420.

5 Hideki ON, Chikahito S, Tateo U. Effect of slag components on reducibility and melt formation of iron ore sinter. ISIJ International. 2002;42(5):558-560. http://dx.doi.org/10.2355/isijinternational.42.558.

6 Sun H, Kunihiko N, Katsumi M. Influence of Slag Composition on Slag–Iron Interfacial Tension. ISIJ International. 2006;46(3):407-412. http://dx.doi.org/10.2355/isijinternational.46.407.

7 Hiroyuki M, Hironori S, Shoji H. Influence of mixing coal composite iron ore hot briquettes on Blast Furnace simulated reaction behavior in a packed mixed bed. ISIJ International. 2011;51(8):1247-1254. http://dx.doi.org/10.2355/isijinternational.51.1247.

8 Yuki T, Tomohiro U, Keiji O, Shoji H. Reaction behavior of coal rich composite Iron ore hot briquettes under load at high temperatures until 1400°C. ISIJ International. 2011;51(8):1240-1246. http://dx.doi.org/10.2355/isijinternational.51.1240.

9 Takashi M, Natsuo I, Yoshiaki H, Kanji T. Influence of gangue composition on melting behavior of coal-reduced iron mixture. ISIJ International. 2004;44(12):2105-2111. http://dx.doi.org/10.2355/isijinternational.44.2105.

10 Shiro W, Kanji T, Hirobumi N, Shigeaki G, Nozomu N, Tetsuro U et al. Development of high ratio coke mixed charging technique to the Blast Furnace. ISIJ International. 2006;46(4):513-522. http://dx.doi.org/10.2355/isijinternational.46.513.

11 Kaushik P, Fruehan RJ. Mixed burden softening and melting phenomena in blast furnace operation Part 3 – Mechanism of burden interaction and melt exudation phenomenon. Ironmaking & Steelmaking. 2007;34(1):10-22. http://dx.doi.org/10.1179/174328106X118161.

12 Wang XL. *Iron and steel metallurgy*. Beijing: Metallurgical Industry Press; 2008.

13 Wu SL, Tuo BY, Zhang LH, Guo L, Wu JL, Zhou Y. Study on influence law of coke reactivity on softening dropping property of ferric burden in blast furnace. Journal of University of Science and Technology Beijing. 2012;30(4):10-22.

Received: 26 Dec. 2012
Accepted: 15 May 2013