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Effect of flux granulometry and other process variables on the sintering of iron ore at high basicity

R. P. BHAGAT

National Metallurgical Laboratory, Jamshedpur - 831 007.

ABSTRACT

Elimination of raw limestone from the blast furnace burden is known to bring a considerable saving in coke rate. In a country like India or elsewhere, the capacity of the sintering plants is limited it is imperative to produce super fluxed sinter and use it in the furnace. The basicity requirement coupled with the higher gangue input through coke and iron ore demands for a greater amount of flux in the mix. This situation is different from the frequently reported practice elsewhere in the world. So the flux size has crucial effect in the sintering. However, this has not been reported adequately. In order to bridge the gap in the literature, sintering study was carried out using factorial design. Five factors were studied at two levels. Data generated through the experiments were analysed using the statistical procedure and the regression equations were established for the following sintering indices in terms of significant factors and interactions. The flux granulometry has crucial role in the production of sinter at basicity level of 3.25. The sintering indices are adversely affected when the sinter mix contains higher amount of -0.5 mm size fraction in it. The thermal and X-ray diffraction analyses of the sinter and return fines sample reveal that the limestone is not properly calcined properly to be assimilated by hematite. A saving in the consumption of coke breeze upto 10% can be achieved through improvement in gasodynamic in the sintering bed when -0.5 mm size fraction in limestone is restricted. Based on the above observation a modification in the existing crushing scheme of limestone are proposed.

INTRODUCTION

Elimination of raw limestone from the blast furnace burden is known to bring a considerable saving in coke rate [1,4]. A reduction in coke rate by about 3.5% in the Bhilai blast furnace is reported when 100 kg/TMH of raw limestone is eliminated by using a greater percentage of super fluxed sinter in the burnden[2]. In a country like India or elsewhere, the capacity of the sintering plants is limited since the available iron ores are rich in Fe and do not require elaborate processing. In view of this it is imperative to produce super-fluxed sinter and use it in the furnace. The basicity requirement coupled with the higher gangue input through coke and iron ore demands for a greater amount of flux in the mix. This situation is different from the frequently reported practice elsewhere in the world where the gangue constituents are considerably lower and so the input of flux. Eventually the situation prevailing under Indian condition has not been reported adequately as regards effect of greater amount of fine sized flux on the sintering indices and desired crushing and sizing scheme of limestone.

A higher amount of –0.5 mm size fraction in the limestone adversely affects its calcination and subsequent assimilation by hematite and other minerals. This is due to the poor accessibility of host gases and consequently poor heat transfer has been observed [5].

The present paper entails to understand some of the problems in the production of superfluxed sinter and outlines remedial measures in improving the sintering efficiency by virtue of modified crushing of limestone.

MATERIALS AND METHODS

Design of Experiment

Sintering study was carried out using factorial design of the type 2^{5-1}. Five factors were studied a the two levels. Table 1 shows the variables studied at the low levels and the parameters which were held constant.

Raw Materials

The raw materials used in the sintering experiment were typical of those commonly used in the sintering plants of Bhilai Steel Plant. The chemical compositions of the raw materials are shown in Table 2. The crushed flux and coke breeze were screened into five size fractions, namely, +3 mm, –3 mm +10 BS mesh, –10 BS mesh + 1 mm, –1 mm + 30BS (0.5 mm) and –30 BS mesh. The individual fractions were mixed in the proportion envisaged in the experimental plan (Table 1) separately for low and high levels. By doing so the blend had the envisaged average size as typically observed from the samples drawn periodically from the sintering plants. The variation in crushing and screening parameters would result in the limestone/coke breeze having different size analyses. Such study (on composite size) has more relevance than frequently reported study on individual size fraction.

Table 1 : Variables and their values at the low and high levels

Factor	Symbol	Variable	Levels Low	High
A	X_1	Basicity ration of sinter	2.5	3.25
B	X_2	Coke in sinter charge, %	5.5	6.5
C	X_3	Size of flux (Dp), mm	0.67	1.47
D	X_4	Size of coke (Dp), mm	0.67	1.47
		Size composition of flux/coke, %		
		+ 3 mm	0	20
		– 3 + 1.67 mm	10	16
		– 1.67 + 1 mm	17	16
		– 1 + 0.5 mm	18	14
		– 0.5 mm	55	34
E	X_5	Bed height, mm	265	315

Parameters are held constant :

Moisture content of sinter charge = 7%

Proportion of return fines = 30%

Size composition of return sintered fines :

– 10 + 5 mm = 45%

– 5 + 3 mm = 25%

– 3 mm = 30%

Suction at the wind box of the pot = 500 m w.c.

Hearth layer on the grate of the pot = 1.5 kg.

Total heat input for ignition = 2400 k.cal/M^2 (approx)

Position of thermocouple from the top = 120 mm

Table 2 : Chemical analysis of raw materials

Raw Material	Chemical Composition (%) Fe	CaO	MgO	SiO_2	Al_2O_3
Iron ore fines (Rajhara mine)	62.85	–	–	2.89	2.94
Iron ore fines (Dalli mine)	59.25	–	–	4.97	5.92
	LOI				
Limestone	40.18	41.70	7.50	5.75	4.29
Dolomite	44.51	30.72	12.99	3.77	2.41
Lime	24.28	58.50	7.42	5.44	3.91
Coke ash	9.73	2.5	1.66	55.79	25.62
	Fe_2O_3				
Coke	V.M.	Ash	Moisture		Carbon
	1.6	29.5	1.3		68.9

Table 3 shows the screen analysis of ore fines.

Table 3 : Screen analysis of iron ore fines

	Size in mm			
Raw Material	−10+5	−5+3	−3+1	−1
Iron ore fines (Rajhara Mine)	11.85	10.80	16.15	61.20
Iron ore fines (Dalli mine)	20.73	16.97	20.41	41.89

Sintering

Sintering was carried out in a sinter pot of 257 mm diameter and 400 mm height with removable grate bars at the bottom. The sinter mix prepared in a disc pelletizer was put into the pot upto desired height and ignited. Vacuum was maintained by operating an exhaust valve till the completion of sintering. Subsequent to the adequate cooling the sinter cake was dislodged and subjected to stabilization by dropping the entire cake two times from a height of two meters on a steel plate. The +10 mm size fraction was subsequently subjected to shatter test. The material was dropped three times on the plate and screened at 10 and 5 mm.

The percentage of +10 mm size fractions following the stabilization and shatter test were reported as yield of sinter after two and five drops, respectively. These were denoted by assigning the subscripts 2 and 5 to the indices. The other sintering indices, like, productivity, return fines generation etc., were calculated from the yield of sinter and reported accordingly.

Analysis of the Factorial Experiment

Data generated by the experiment were analysed using statistical procedures. Firstly the analysis of the data for each of response variables was carried out following Yates's method to find out the estimates of effects and sum of squares. The residual (error) mean square was computed from the data generated by repeated experiments at the base level using standard statistical procedures.

Secondly, the results from the experiment were used to determine a first order empirical model of the sintering process.

RESULTS AND DISCUSSION

Empirical Equations

Table 4 shows the empirical regression equations relating the response variables with the independent variables and the interactions which are significant upto to ten percent. The variables are written in coded form (X_i. These are related to the variables in natural form (x_i) by the equations which are also mentioned in the foot note of the Table.

Table 4 : Empirical equations of the dependent variables with respect to the significant independent variables and two factor interactions

	Equation	Index Value			
		Minimum		Maximum	
		Obs.	Calc.	Obs.	Calc.
A.	Vertical speed of sintering (VSS), mm/min. $VSS = 18.04 + 2.846\ X_3 - 2.449\ X_5 + 1.174\ (X_1.X_3) + 1.056\ X_2$	9.61	10.51	25.50	25.56
B.	Yield at stabilization of sinter by 2 drops, 5 drops [Yield (2), Yield (5)],% Yield (2) = $50.48 - 10.243\ X_1 + 8.462\ X_3 + 6.914\ (X_1.X_3) + 2.321(X_1.X_2) + 1.87\ X_2$	18.55	20.66	63.79	62.54
	Yield (5) = $39.30 - 8.06\ X_1 + 7.81\ X_3 + 6.20\ (X_1.X_3) + 2.26\ (X_1X_2) + 1.6\ X_5 + 1.54\ X_2$	12.94	11.85	52.26	49.84
C.	Porductivity at stabilization of sinter by 2 drops, 5 drops [Prod(2), Prod(5)], $t/m^2.hr$ Prod. (2) = $0.708 + 0.219\ X_3 - 0.117\ X_1 + 0.102\ (X_1.X_3) - 0.072\ X_5 + 0.036\ X_2 + 0.028\ (X_1.X_2)$	0.131	0.134	1.041	1.006
	Prod.(5) -= $0.557 + 0.181\ X_3 - 0.100\ X_1 + 0.094\ (X_1.X_3) - 0.043\ X_5 + 0.033\ X_2$	0.092	0.106	0.815	0.809
D.	Shatter Index (SI), % $SI = 76.27 + 3.617\ X_3 + 2.991\ X_5 + 2.95\ (X_1.X_3) - 2.45\ X_1 + 1.41\ (X_1.X_2)$	56.75	68.83	82.76	82.45

$x_1 = 0.375X_1 + 2.875$; $x_2 = 0.5X_2 + 6.0$; $x_3 = 0.47X_3 + 1.07$; $x_4 = 0.47X_4 + 1.07$; $x_5 = 25X_5 + 290$

Effect of Basicity, Flux Size and Their Interaction

The present investigation shows that flux grain size, basicity ratio (CaO/SiO_2) of sinter mix and their interaction were significant parameters. Fig. 1 shows the effects of these parameters on the sintering indices.

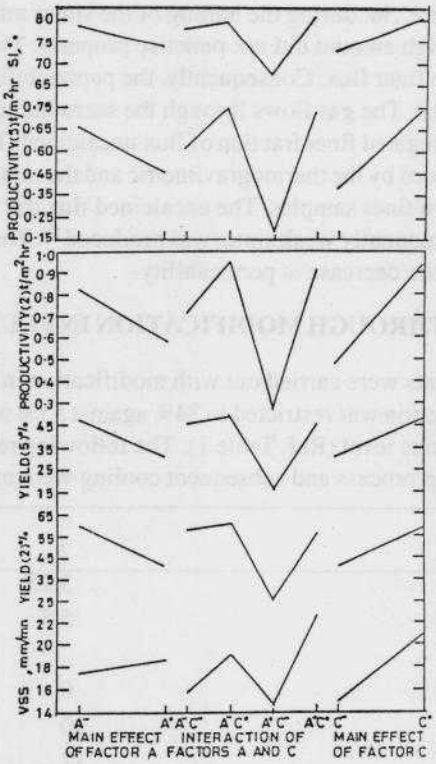

Fig. 1 : Dependence of the sintering indices on basicity ratio (A), flux size (C) and their inter action (AC).

Fig. 1 shows that the interaction effect of the factors, namely, basicity ratio and flux size is significant. Better sintering indices were obtained at the high level of basicity ratio only when the flux size is at the high level. This typical observation differs from the commonly reported practice elsewhere in abroad where better sintering indices are reported through use of flux of finer grain size. The proportion of limestone in the sinter mix, elsewhere is low because of

- lower basicity requirement
- lower gangue constituent.

On the other hand, sintering plants in India have to produce superfluxed sinter in order to eliminate limestone from the blast furnace burden. The amount of gangue ($SiO_2 + Al_2O_3$) content in the raw materials is also high. These factors lead to the high proportion of lux in the sinter mix. Flux has poor balling characteristics as compared to iron ore. So, during the balling of the sinter mix the finer fraction of flux, which is in high amount did not pelletise properly. This situation lead to the segregation of the finer flux. Consequently, the permeability of the sinter mix was adversely affected. The gas flows through the surrounding of the larger particles leaving the segregated finer fraction of flux uncalcined. The above phenomenon has been confirmed by the thermogravimetric and the mineralogical analyses of the sinter and return fines samples. The uncalcined flux did not assimilate with the hematite and consequently weak sinter was produced [6]. The speed of sintering was also low due to the decrease is permeability.

IMPROVEMENT THROUGH MODIFICATION IN FLUX GRAIN SIZE [5]

Typical experiments were carried out with modification in the flux grain size. The –0.5 mm size fraction was restricted to 34% against 55% which was observed with the flux of low size level (Ref. Table 1). The following result shows that the efficiency of sintering process and subsequent cooling were markedly improved.

	Experiment No.	
Test Conditions	2	2 (mod.)
Basicity ratio	3.25	3.25
Coke content (%)	5.5	5.5
Size of Flux (%)		
+ 3 mm	0	0
– 3 + 1.67 mm	10	14.6
– 1.67 + 1 mm	17	25.0
– 1 + 0.5 mm	18	26.4
– 0.5 mm	55	34
Sintering Indices		
Vertical speed of sintering, m/min	9.61	21.18
Yield of sinter after 5 drops, % + 10 mm	13.12	54.50
Productivity of sinter, $T/m^{2}*$ hr	0.092	0.932
Shatter Index, (%)	70.73	86.51

Suggestion for Improvement

From the above observation, it is apparent that both –0.5 mm and +3 mm size fractions in flux should be restricted, that is the frequency size curve should be narrowed rather than flattened one. Measures to achieve so are outlined below :

(a) Restricting –3 mm Size Fraction in Feed :

Screening out the –3mm size fraction before crusher could eliminate further breakage of that product resulting in less fine generation. The –3 mm size fraction, which amount to 5 to 10% in case of lump and 20 to 25% in case of limestone chips, could be redirected directly to the point of sinter mix. By virtue of this, load on crusher is reduced.

(b) Adopting Two Stage Crushing Scheme with Classification in Place of One:

The +5- mm size fraction constitutes as high as 10% of the feed material. Therefore with one stage crushing the reduction ratios is (50/3) = 17. With high reduction ratio (for efficient operation it should be around 4), the material which undergoes crushing has to remain for a longer duration resulting in over crushing.

The +12.5 mm size fraction consists of 70–80% of the feed. The problem of over crushing could be sufficiently reduced by adopting two stage crushing scheme:

- the primary one with a discharge gap of 12.5 mm (reduction ratio 50/12.5 = 4), and
- secondary one with a discharge gap of 3 mm (reduction ratio 12.5/3 = 4.2).

The product of primary crusher after screening out 3 mm size fraction could be fed to the secondary one.

Following this scheme also implied of more homogenized breakage.

(c) Improving the condition of Hammer Mill [7]:

Hammer wear unevenly, largely at the edges. Especially in the case where the feed encounters horizontally moving hammers, proper care must be undertaken to harmonize the feed velocity with hammer velocity.

Impact should preferably be distributed so as to hit the striking faces of the hammers in full, rather than letting feed particles glance off hammer edges. In the later case, notably the hammer merely hurt away but do not break most of the particles they strike, the discharge will be poor in fines and rich in coarser particles.

(d) Improvement in Screen Effectiveness:

The classification is affected by one or more of the following :

i. Faulty design/layout of the screen set up.
ii. Higher material flow compared to the screening area.
iii. Blinding of the screen aperture.
iv. Wearing/tearing out the screen aperture.

Improvement in the granulometry of the limestone could also be attained through improved classification.

CONCLUSIONS

a) The flux granulometry plays a crucial role while super fluxed sinter is produced. The sintering indices are much adversely affected when the sinter mix contains too much amount of 0.5 mm size fraction of flux.

b) Remarkable improvement in the sintering indices and significant saving in specific coke consumption can be achieved by restricting the amount of 0.5 mm size fraction of flux in the sinter mix.

c) It requires special care in crushing and sizing of flux for the sintering plants in India. Salient measures have been suggested in this regard.

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