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Composite Pre-Reduced Pellet Quality as Affected by Reductant Reactivity

R. C. Gupta[1)] and S. N. Misra[2)]

1) Dept. Metallurgical Engg, IT- Banaras Hindu University, Varanasi-221005, India
2) Presently with Aparant Steel P Ltd, Panjaji-403001,Goa, India

The composite pre-reduced (CPR) pellets have been developed to utilise steel plant waste fines (eg. Iron ore, flue dust, mill scale, coke, coal, lime etc.) into value added product suitable for blast furnace feed as metallised burden. This requires good reduction (%R), appreciable metallisation ($\%Fe_{met}$), sufficient handling strength and low cost for acceptance as blast furnace feed. These properties could be achieved by optimising the process parameters. In this paper, the effect of reductant reactivity has been observed by studying the reduction behaviour of ore-char mixed composite pellet due to powdered coke, coal and woodchar while keeping the molar ratio of Fe_2O_3 : C as 1: 3 and identical heating schedule. It was observed that highly reactive form of carbon in woodchar rendered more reduction (~ 46% R) compared to coke (22%R) and coal (39.5%R) but woodchar also seem to cause severe pellet cracking than coke or coal. The cracking is mainly due to whisker type of iron growth caused by rapid reduction rate.

KEY WORDS : CPR pellet; Composite pellet; Double layer pellet; Ore-char mixed pellet; Reactivity, Reductant; DRI.

1. Introduction

Several authors[1-4)] have suggested the use of metallised feed for the blast furnace to minimise the coke consumption which is getting rare and expensive. Based on these studies various plants in the world made pilot plant trials[5-9)] and proved that the use of metallised feed upto 30% can give substantial saving in coke with higher metal production from blast furnaces. Inspite of such theoretical and industrial experiences the metallised burden is not used today since it failed on economic ground.

The CPR (composite pre-reduced) pellets have been developed for the use in blast furnaces with a cost projection to justify its use. It consist of highly metallised sponge iron core encased in a hard and sintered shell of iron ore which is partially reduced (Fig. 1). The objective, principle and advantages of developing CPR pellets have been explained in previous papers[10-12)]. The mechanism of reduction by carbon present in the core is given in paper by Misra and Gupta [13)].

The efforts made by Gupta[10)] and earlier workers[14)] failed initially due to pellet cracking while firing rendering very little reduction and burning away all added carbon in the pellet. The cursory examination indicated the possibility of pressure exerted by the escaping volatile matter in the reductant to be responsible for breakage, however, the detailed study of the cracked pellets by observing SEM micrographs revealed that the manner of reduction process was responsible for pellet cracking. As a result of detailed study and optimisation of process parameters it was possible to prepare good

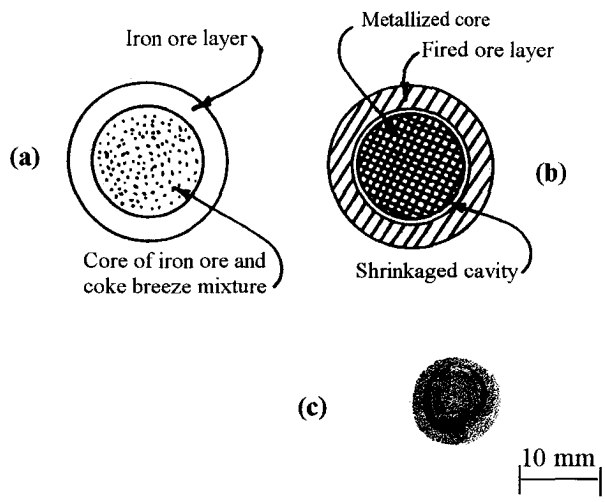

Fig. 1. Cross sectional view of CPR pellet
a) before heating (schematic)
b) after heating (schematic)
c) after heating (photo-broken pellet showing sponge iron encased in shell of ore)

CPR pellets with 50-60%R, 30-40% metallisation, 120 kg strength and 94% shatter strength which could be used as a blast furnace feed[15]. The techno-economics and feasibility of the process have been presented in Perth[16-17] meeting of AusIMM.

The reduction rate of carbon mixed pellet depends on various factors e.g. the ratio of carbon added, type of carbon used, rate of heating during firing and the temperature adopted for the purpose etc. In this paper the effect of type of carbon used has been shown on the pellet reduction and cracking behaviour which is important for CPR pellet quality.

2. Experimental Procedure

The raw material used included iron ore fines having particle size - 210 μm (91.13% Fe_2O_3, 2.52% Al_2O_3,1.4% SiO_2, 4.95% LOI) and three different reductants (coke, coal and woodchar) in powder (-72 #) form with reactivity ranging ~ 0.1 to 10 × 10^{-4} s^{-1}. The reactivity and proximate analysis of these reductants are given in Table 1. The iron ore and reductant mixed in 1:3 mol ratio was pelletised by hand rolling to about 14 mm size pellet (as core). This core pellet was coated with iron ore only by hand rolling rendering total pellet dia as 18 mm. This green composite pellet was kept in crucible of a TG set-up (Fig. 2) to be heated without maintaining external inert/ reducing atmosphere. The bottom inlet and top outlet were open to atmosphere for free air flow. The heating schedule had a pre-heating rate of 110 K ks^{-1}; heating time - 2.4 ks at 1323 K with total firing time as 11.8 ks. The heating program and weight loss of the pellet with heating time is shown in Fig. 3. The pellets were examined for their appearance after cooling and their %R was calculated from observed weight loss. The fired pellet was then crushed to make powder for estimating residual carbon and total iron in reduced pellet.

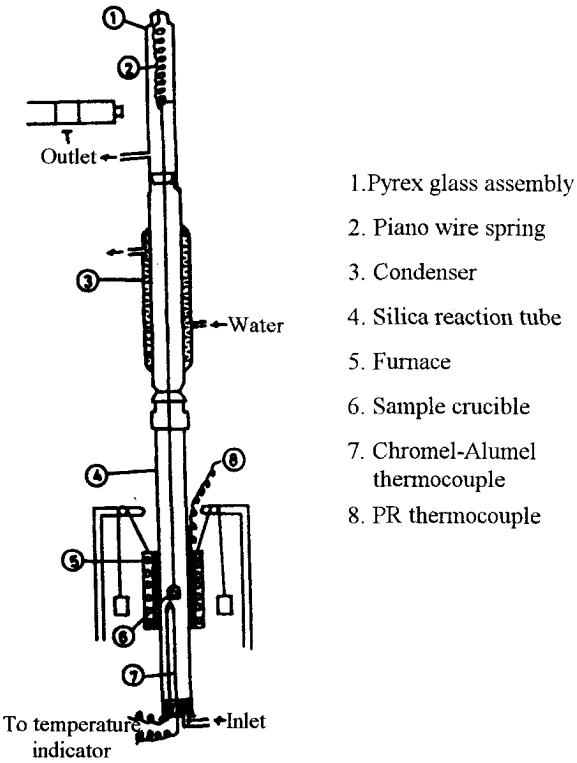

Fig. 2. TG-Setup for heating and reducing the pellet in air

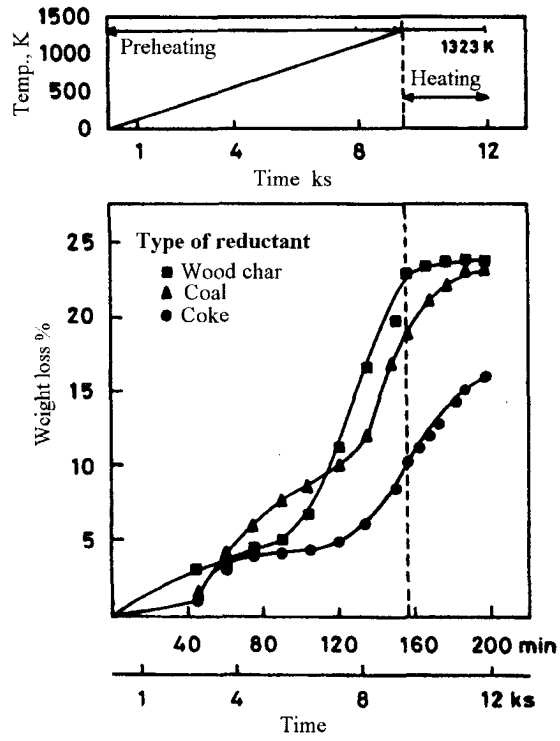

Fig. 3 Heating program and weight loss of pellet during reduction

3. Results & Discussion

It was observed that pellet using wood char was relatively reduced to higher reduction degree (45%R) with maximum cracks (burst open) compared to coal bearing pellet (39.5% R) having minor cracks. The pellet containing coke fine was reduced to 22% R without having any cracks. These observations are given in Table 2. It is well known that in ore coal mixed pellets the carbon is gassified to CO which causes reduction of iron oxide and generates CO_2 which by reacting with carbon is regassified to CO for further reduction of iron oxide. This reduction of iron oxide and gasification of carbon continues till the reactants remain. The rapid gassification of more reactive wood char (~ 9.0 × 10^{-4} s^{-1}) would result in higher rate of reduction (5.0 mg s^{-1}). Sharma et al reported[18] higher swelling % with increased reduction rate (upto 2% per min) by CO. This higher swelling is associated with the formation of whisker type iron which appear to push apart resulting in severe cracking. The higher volatile matter in wood char escaping rapidly during heating could also be held responsible for cracking to some extent but not completely since pellet using coal with higher (33.21%) volatile matter content than wood char (21.71%) showed less cracking (Table 2) during identical heating cycle.

The absence of pellet cracking is vital for pellet strength which is essential for its use as a blast furnace feed. Such crack free pellet was obtained with the use of coke fine having low reactivity (~ 0.30 × 10^{-4} s^{-1}). The Fig. 4 gives the SEM micrographs of pellets showing absence of whiskers in pellet using coke and some whiskers in mildly cracked pellet using coal as reductant. The micrograph of the severely cracked pellet using woodchar was not possible as it was too fragile to be handled.

Table 1. Reactivity and proximate analysis of the reductant

Parameters	Coke	Coal	Wood char
Volatile Matter %	05.63	33.21	21.71
Ash %	34.64	21.58	04.00
Fixed Carbon %	58.28	40.16	68.56
Reactivity (× 10^{-4} s^{-1})	~0.30	~0.80	~9.00

Table 2 Effect of Reductant Type on CPR Pellet Quality

Parameters	Coke	Coal	Wood char
Fe_2O_3 : C in core pellet	1 : 3	1 : 3	1 : 3
C % in total pellet	05.48	04.93	05.70
Observations for composite pellet after heating			
Unreacted C% in pellet	0.33	0.25	0.20
Reduction % (R)	22.0	39.5	45.9
Fraction Reacted (f)	0.55	0.80	0.85
Average Reduction Rate mg min^{-1} (see appendix)	02.4	02.1	05.00
State of Pellet	no crack	few crack	burst open

The degree of reduction (Table 2) for a given time was found more for pellet having wood char (45.9 % R) due to rapid rate of reduction compared to pellet having coke fine (22.0% R). However, this is no poor reflection for the use of coke fine as degree of reduction could be enhanced by controlling time and temperature of reduction. The use of highly reactive reductant needs care to avoid cracking by using additives to avoid the whisker formation. Using this experience CPR pellets with very high degree reduction (70%R) and metallisation (over 60% Fe metallic) having 120 kg strength could be made in larger quantity (~ more than 500 kg) using various type of raw materials including coke fine which is given in a recent report [6].

4. Conclusions

(1) The reactivity of the reductant affects the quality of CPR pellets made from iron ore and coal/coke fine mixture.

(2) Higher reactivity (~ 10 × 10^{-4} s^{-1}) of the reductant renders higher rate of CO gas generation and reduction rate resulting in the formation of iron whiskers causing pellet cracking and poor strength.

(3) Lower (~ 0.3 × 10^{-4} s^{-1}) reactivity of the reductant renders reduction without pellet cracking.

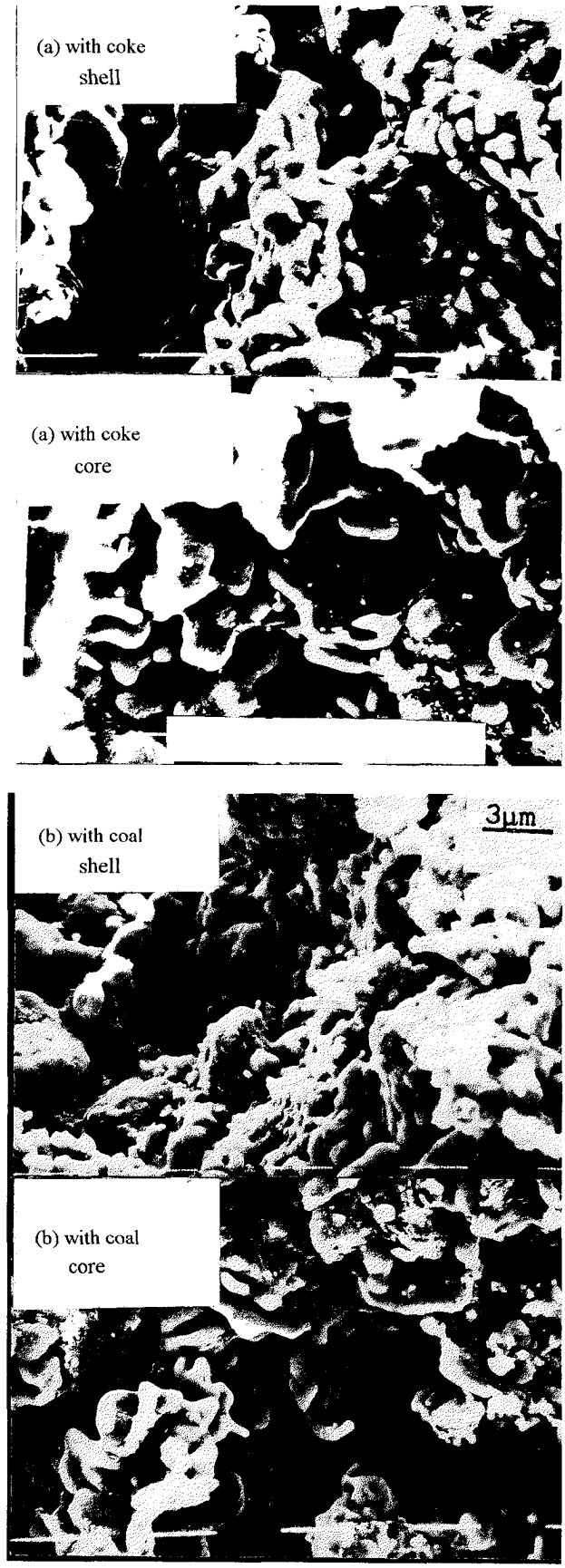

Fig. 4. SEM micrograph of CPR pellet sintered at 1323K with coke (a) and coal (b) showing absence of whiskers in pellet with coke in core and shell region

(4) Good degree of reduction and good strength in CPR pellet could be obtained by optimisation of process parameters.

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APPENDIX

Calculation of Average Reduction Rate, Degree of Reduction

The fig. 3 showing weight loss percent with heating time only gives the relative picture that woodchar renders maximum reduction while coke gives least. The table 3 gives a stoichiometric mass balance for one typical experiment using wood char as reductant.

$$\text{The degree of reduction} = \frac{\text{Weight of oxygen removed}}{\text{Weight of oxygen present}} \times 100 \quad \text{The rate of reduction} = \frac{\text{Weight of oxygen removed (mg)}}{\text{Reduction time (min or s)}}$$

Table 3. A Typical Stoichiometric Mass Balance of CPR Pellet

Pellet Details	
Iron Ore – Carbon ratio	1 : 3
Reductant Carbon type	Wood Char
Wood Char Analysis	21.7% Volatile Matter, 5.73% Moisture, 4.0% Ash, 68.57% Fixed Carbon
Iron Ore Coating Thickness	2 mm
Iron Ore Analysis	63.7% Fe, 27.3% O, 3.9% Gangue, 4.9% LOI

Pellet Firing Detail	
Pre-heating time	9.4 ks
Heating time	2.4 ks
Total time	11.8 ks
Heating temperature	1323 K
Pre-heating rate	110K ks^{-1}
Pellet Weights Recorded	
A – Core Pellet (Unfired)	
B – Core + Coating (Unfired)	
C – Core + Coating (Fired)	

Constituents	Unfired Pellet Weight			Fired Pellet Weight		
	Core (A)	Coating (B-A)	Total (B)	Core	Coating	Total (C)
VM + Moisture (gm)	0.1974	–	0.1974	–	–	–
LOI (gm)	0.1194	0.2728	0.3922	–	–	–
Carbon (gm)	0.4934	–	0.4934	0.0136	–	0.0136
Oxygen (gm)	0.6595	1.5070	2.1665	0	1.17	1.17
Ore Gangue (gm)	0.0945	0.2161	0.3106	0.0945	0.2161	0.3106
Coal Ash (gm)	0.0287	–	0.0287	0.0287	–	0.0287
Iron (gm)	1.5387	3.5163	5.0550	1.5387	3.5163	5.0550
Total wt. (gm)	3.1316	5.5122	8.6438	1.6755	4.9124	6.5779
Carbon %	15.75		5.70	0.78	–	0.207
Iron %	49.13	63.79	58.48	91.85	71.58	78.83
Wt. loss %						25.82
Reduction %				100	22.36	45.99

$$\text{Reduction Rate} = \frac{\text{Total oxygen removed } (2.1665 - 1.17)\text{ g}}{\text{Total reduction time 196 min or 11.8 ks}} = 5 \text{ mg min}^{-1} \text{ or } 0.08 \text{ mg s}^{-1}$$