Pelletisation Behavior of Fluxed Iron Ore Pellets of Varying Basicities Made with Waste Fines

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Abstract - The present study deals with the utilization of fines generated from comminution process (crushing, grinding and screening) of the Run of Mines into value added products i.e. fluxed iron ore pellets. The study comprises to understand the physical and mechanical behavior of five distinguished chemical compositions of green and dried iron ore pellets with respect to a typical Mini Blast furnace (MBF) burden data and furnace operating parameter. The maximum basicity of pellets was calculated 2.37 to make slag neutral when blast furnace runs at 100% high ash coke (avg. ash content= 29%). The crushing strength and drop number of various green pellets were measured. Green Crushing Strength was decreased with increasing lime fines. The addition of lime fines as a burnt lime, which has acicular structure creates less plasticity and brittle like fracture occurred. Due to formation of hard $CaCO_3$ layer on the surface, after increasing lime contain crushing strength was increased in the air and oven dry pellets with respect to acid pellet (0% lime fines addition).

Key Words - *Agglomeration, Crushing strength, Burnt Lime, Fluxed Pellets, Waste Fines*

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I. INTRODUCTION

For the production of suitable sized feed materials (-40mm to +15mm) for Blast Furnace, during comminution process (crushing, grinding and screening) of the Run of Mines (ROM) generates a lot of fines (-15mm) almost 50% of the total output of sized iron ore and almost 50% of total lime made (Mandal et al., 2012; IMY, 2011; UKMY, 2006).

India is the 4th largest steel producer in the world. India produced 76.715 million tons of crude steel in the year of 2012 where world steel production was 1510.223 million tons against 72.7 million tons of steel in the year of 2011 where world produced 1490.060 million tons of steel (Mandal et al., 2012; C.S. Production, 2012). It is being expected that Indian steel production will grow 10% during 2010-2013 (Mandal et al., 2012). World Blast Furnace Iron (BFI) Production in the year of 2012 was total 1100.674 million tons by 38 countries in which India produced 42.258 million tons occupying also 4th position in the world (BFI Production, 2012), whereas World Direct Reduced Iron (DRI) Production in the year of 2012 was total 55.361 million tons by 11 countries in which India produced 19.799 million tons occupying 1st position (DRI Production, 2012).

For making Blast furnace feed material from ROM ore, materials are subjected to Mineral Beneficiation Operation (Crushing, Grinding, Sizing, Washing etc.). According to Indian Bureau Of Mines, Nagpur, the total output of 208 million tones of ROM in which, lump iron ore constituted 82.2 million tones or about 39.5%, fines 125.1 million tones or about 60.2% and concentrates 0.7 million tones or about 0.3% of the total output of iron ore lumps (IMY, 2011), 20% of total coal mined and 22.5 % quarry fines of lime stone (Quarry fines are those fines generated by processes related to blasting, processing, handling and transportation) i.e. almost 50% of total lime made (UKMY, 2006). The particles, smaller than 3 mm size, are generated commonly termed as "Waste Fines". These fines are partially utilized in the processes like Pellet Making, Power Plant, and Desulphurization respectively. The disposal of these solid waste fines increases the cost; render material loss and

posses many environmental issues. The conversion of solid waste fines into value added products for use is the policy of the day.

Critical analysis of the reported literature indicates that problems of lump lime charging in the BOF like high melting point and slow dissolution could be overcome by the development of suitable lime-fluxed iron oxide agglomerates viz. sinter, briquette, or pellet. Additionally, preparation of such agglomerates may provide an opportunity toward proper utilization of iron ore fines and limestone fines simultaneously (Pal et al., 2011)

In conventional method, Lime Stone and Dolomite in bulk are being used as flux inside the blast furnace. The main problem of adding these as a flux is 'alkali loading' inside the furnace. The alkali cycle inside the Blast Furnace is maintained in between 900°C-1100°C (Biswas, 1981). This problem could be minimized by using hardened fluxed iron ore pellets because during hardening (>1100°C) operation of the fluxed pellets, alkali (Na_2O, K_2O) got evaporated. Since the last three decades, fluxed iron ore pellets have been slowly taking over the load of acid pellets as the primary burden around the world. In fluxed pellets, limestone and dolomite are added to the magnetite or hematite concentrate, which already contains silica as a gangue. One of the primary strength forming mechanisms in iron ore pellets is the formation of liquid bridges between the iron oxide particles at high temperature. Adding of lime to iron ore pellets changes the chemistry of these liquid bridges from iron silicates to iron calcium silicates (Firth et al., 2008).

It has been proven theoretically and experimentally that the use of 10%-30% DRI in blast furnace along with iron ore or sinter results in lowering coke rate and higher productivity (Gupta, 1999). As the amount of coke required for melting is three times less than the amount of coke required for smelting (Schriefer, 1995).

A valuable observation has been made by Steel Authority of India Ltd. that the use of sponge iron in BFs may not pick up very strongly at present, but, in the medium term, it is expected to change in favour of charging sponge iron in blast furnaces (EBR, 2010). In addition, the use of DRI also improves the production rate, variation in the hot metal composition and decreases the amount of flux required for fluxing (Kaushik and Fruehan, 2006a; Kunitomo et al., 2006; Sakamoto et al., 1988; Tang M., 1999). It has been reported that the use of DRI in blast furnace not only reduces energy consumption in the existing blast furnace iron making process but also reduces the energy consumption related to Carbon Dioxide emission in the total hot metal production processes, including the partial reduction process (Nogami et al., 2006; Kaushik and Fruehan, 2006a; Kaushik, and Fruehan., 2006b).

The present study deals with the making of fluxed pellets for gainful utilization of these materials to get fluxed iron ore pellets as Blast Furnace feed material comparing with the typical burden data when the furnace was running at 100% lump iron ore (average of three months) of an Indian MBF. Lime fines were added with the required proportion of iron ore fines to get the different basicity in contrast with the parent burden used when furnace runs at different composition and proportion (blending) of coke used. It was tested for its physical and mechanical properties of different basicity pellets.

II. EXPERIMENTAL

A. Raw materials

In the present investigation, we used iron ore from Orissa (India) and limestone Rajasthan mines (India). Calcined (burnt) lime and iron ore samples were ground separately in a laboratory ball mill of 5 kg capacity and all samples were screened through BS-72 mesh (0.2mm) sieve separately.

B. Characterization of Raw Materials

Chemical Analysis of iron ore and lime stone were done with weight method. Results are shown in Table I.

TABLE I
CHEMICAL ANALYSIS OF IRON ORE AND LIME STONE

Raw Material	Fe (T)	SiO_2	Al_2O_3	CaO	MgO	Mn	P	S	Fe_2O_3	Alkali	LOI
Iron Ore fines	64	1.8	2.6	-	0.08	0.07	0.03	0.001	-	0.1	2.5
Lime Stone fines	-	1.2	1	52	2	-	0.022		0.5	0.23	40

From the XRD analysis (On model no Rigaku D-MAX IIIB) of iron ore and lime fines it was observed that % Fe_2O_3 in iron ore was around 95% which indicates the iron ore was as hematite and soft in nature and also burnt lime powder used was least amount of un carbonized $CaCO_3$ (i.e. <5) (Mandal et al., 2012).

C. Calculation of lime addition

For the present study we were taking in consideration of a typical Indian MBF operating data and chemical analysis (average of three months of September, October and November) to determine the maximum pellet basicity, which are given in Table II.

TABLE II
PARAMETERS OF MBF TAKING UNDER CONSIDERATION

	Coke used		H.M analysis	
Type	Low Ash	High Ash	C	4.3
Avg. Ash	14	29	Si	2
SiO_2 in Ash	48	54	S	0.05
Coke rate (dry), when 100% used in burden	640	765	Mn	0.8
			P	0.05
			Fe	92.8

In the case of using in 100% low ash coke in the burden, Dry Coke Rate lies around 640kg/THM, Ash in the Low ash coke 14% and SiO_2 contain in Low Ash coke ash is 48% , So SiO_2 input through coke and iron ore to produce 1

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ton hot metal will be 640×14%×48%=43.008 kg, and 1450×1.8%=26.10kg respectively. So, total SiO_2 will be 43.008+26.10= 69.108 kg. But Silicon in the hot metal is 2%, means 1000×2%= 20 kg Silicon inside the hot metal which came from SiO_2 contain of the burden, that is equivalent to (60 × 20)/28=42.86 kg of SiO_2. So net SiO_2, remaining in burden will be 69.108kg - 42.86kg= 26.25kg, which is equivalent to CaO requires, to neutralize the basicity to form slag chemistry inside the blast furnace neutral (B_1=1). So lime fines are to be added in pellets will be (56.7 × 26.25)/52= 28.62 kg. But if we consider the SiO_2 inside the Lime fines also then, SiO_2 content in lime fines will be (1.2 × 28.62)/56.7= 0.61kg. So total SiO_2 input from all sources is (26.25 + 0.61) kg = 26.86kg, which is equivalent to CaO requires to neutralize the basicity (B_1=1). So total lime fines are to be added is (56.7 × 26.86)/52= 29.29kg for making one ton of liquid iron. So lime fines are to be added in the pellets to neutralize the burden basicity (B_1=1) = (29.29 × 100)/1450= 2.02 ~2% the same way if we use 100% High Ash coke (where, Dry coke rate= 765kg, ash in the High Ash coke= 29% and SiO_2 contain in ash= 54%) in the burden we have to add 7.93%~ 8% of lime fines. For that reason, for the present study we took the lime fines content 2% minimum and 8% maximum. But in practical purpose, except any circumstances arise, 100% Low ash or high ash coke is not used in burden. Coke is blended in required proportion. So 4% and 6% lime fines are added in the pellets. After adding lime fines pellet basicity shown in the Table III. (Iron ore rate: Iron ore and Hot metal have 64% and 93.52%Fe, respectively. So for making one ton of hot metal iron ore required = [1/ {(1/92.8%) × 64%X1000}] × 1000×1000 =1450kg/ THM)

TABLE III
COMPOSITION OF GREEN PELLETS

Optimum Moisture Content (%)	Iron ore (%)	Lime Fines Addition (%)	SiO_2 input (%)	CaO input (%)	Pellets Basicity (B_1)
14	100	0	1.8	0	≈0
16	98	2	1.788	1.04	0.58
17	96	4	1.776	2.08	1.17
18	94	6	1.764	3.12	1.77
20	92	8	1.752	4.16	2.37

D. Procedure

Green pellets of around 18 mm size were made with by prolonged hand rolling of moistened iron ore fines of BS -72 mesh size without bentonite as per flow chart (Fig. 1). The disadvantages of unwanted impurities by using bentonite were discussed in several studies. For instance, the addition of 1% bentonite, containing 85% SiO_2+Al_2O_3, decreases the pellet's iron content to 0.6% (De Souza et al., 1984).

E. Determination of optimum moisture content

Optimum moisture content test were performed for iron ore pellets at different lime addition (0%, 2%, 4%, 6% and 8 %) where maximum strength was analyzed (Fig. 2). Green pellets of around 18 mm size were made with optimum water content by prolonged hand rolling of moistened iron ore fines of BS -72 mesh size without bentonite as per flow chart (Fig. 1).
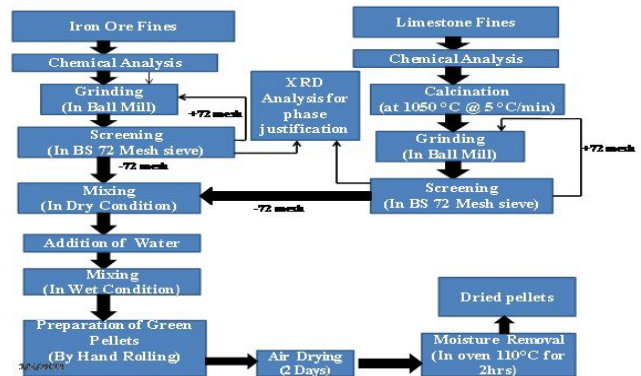

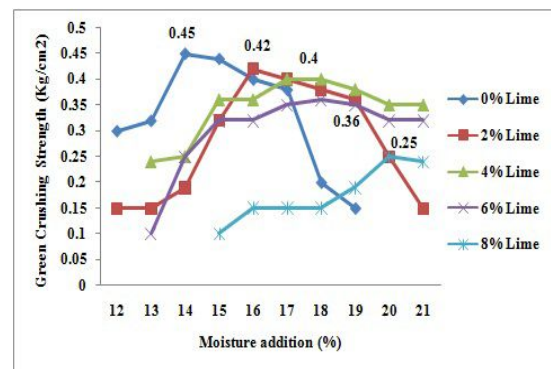Fig. 1 Process flow chart of preparation of pellets

Fig. 2 crushing strength at different moisture

F. Testing of Green iron ore pellets
1) Strength: Green pellets of around 18 mm size were tested for crushing strength with the help of a 'Green crushing strength measurement setup' as shown in Fig. 3. Drop strength was measured by dropping the pellets at a height of 450 mm over a steel surface until break (Gupta, 2010). Properties of different types of green iron ore pellets were given in Table II.
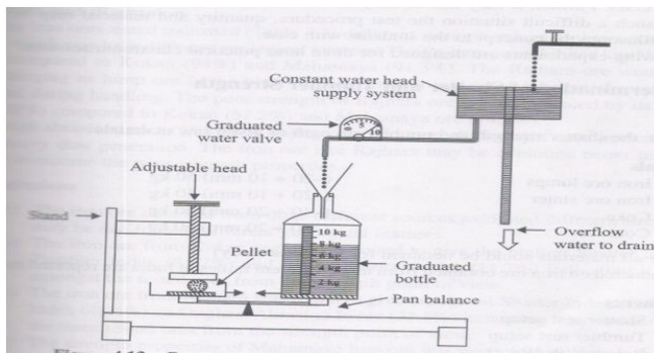
Fig. 3 Green crushing strength measurement set up (Gupta, 2010)

The green pellets were air dried for two days to get moisture free surface and sufficient strength for further treatment. Three pellets of each composition were taken out for testing purpose. Rest pellets were dried at 110°C for 2 hrs in an oven and similarly 3 pellets of each composition taken out for testing purpose. These oven dried pellets were then kept in desiccators for its characterization (crushing strength and microstructure). Dried pellets (air and oven dried) are subjected to compressive load in low range UTM (AGS-5kND, make SHIMADZU) for strength measurement.

TABLE II
COMPOSITION OF GREEN PELLETS

Optimum Moisture Content (%)	Iron ore (%)	Lime Fines Addition (%)	SiO_2 input (%)	CaO input (%)	Pellets Basicity (B_1)
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20	92	8	1.752	4.16	2.37

2) Microstructure: Dried pellets are subjected under SEM (FEI Quanta-200FEG) at 20kv on scan rate 10μs with ETD detector, to observe the outer surface of the pellets of higher basicity pellet for determining the lime fines distribution and porosities as well as formation of any $CaCO_3$ layer over the surface.

III. RESULTS AND DISCUSSION
A. Characteristics of Raw Materials

Qualities of burden materials affect the economy, output, and efficiency of the furnace operation. The chemical analysis of iron ores and lime stone under investigation were listed in Table I. The value of iron content in the iron ore was 64% and 52% CaO in Lime Stone. Data for the mineralogical composition indicated that the gangue materials in the iron ore mainly alumina and silica with a negligible amount of MgO, Mn, P, S and alkali.

The XRD analysis of iron ore (not seen) reveals that % Fe_2O_3 in iron ore was around 95%. It means that iron ore was as hematite and soft in nature. Similarly XRD analysis of lime fines was indicated the different phases present in burnt lime. $CaCO_3$ was observed very less in quantity (i.e. <5). It could be concluded that the burnt lime has only CaO (Mandal et al., 2012).

B. Physical and Mechanical Properties
1) Fracture behavior of green pellets: During water addition for making green pellets with burnt lime, huge steam formed due to exothermic reaction of burnt lime with water. The making of pellets became difficult due to hot steam exit from the pellets. During crushing strength measurement of green pellets, it was observed that in acid pellets, crack initiates and propagate slowly until fracture. But increasing lime content it was observed that crack initiates and propagate instantly and fracture occurred without warning (Fig. 5). It means that increasing lime content decreases the plasticity and fractured occurred like brittle in nature. The SEM micrograph of lime fines particle reveals that the acicular/ needle like structure of the lime fines particles, (Fig 4) which lowers the plasticity inside the pellets and responsible for brittle like fracture. In the case of burnt lime added pellets, free lime particles were observed on the surface of pellets (Fig. 5 and 6).
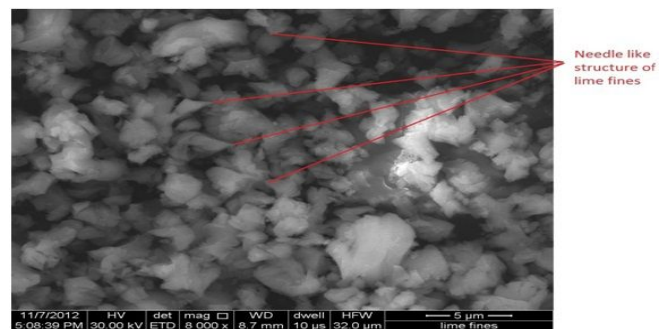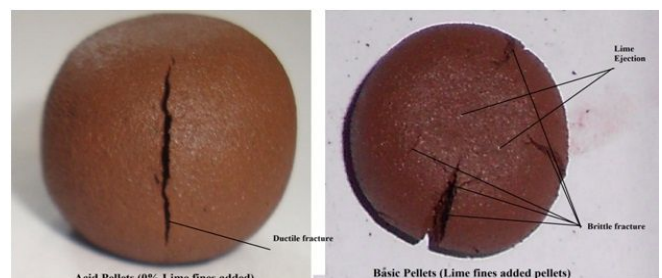

Fig 4 SEM micrograph of Lime fines

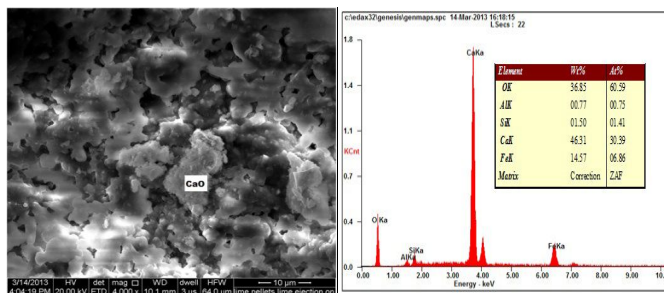Fig 5 Fracture behavior and lime ejection in green iron ore pellets

Fig 6 SEM and EDAX analysis of high basicity pellets of outer surfaces (lime ejection)

2) Strength: From the result it was observed that the green crushing strength as well as drop number of pellets was decreased with increasing lime content because of decreasing its plasticity. These decreasing trends also reported by previous authors (Umadevi et al, 2011). But increasing lime content, the calcium hydroxide of the pellet reacts with environmental CO_2 and formed hard $CaCO_3$ (Fig. 7), which increased its content on the surface of the green pellet which enhanced the air dried crushing strength (Patil, et al, 1980). For that reason whether increasing lime content Green Crushing strength was decreased on the other hand it was increased for air dried pellets (Fig. 8). The crushing strength of air dried, oven dried samples were increased respectively (Fig. 8).
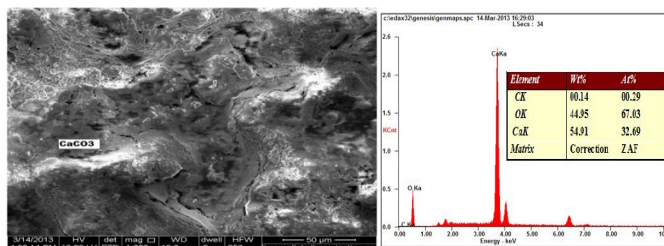

Fig 7 Formation of $CaCO_3$ over the surface responsible for increasing green crushing strength of high basic pellets
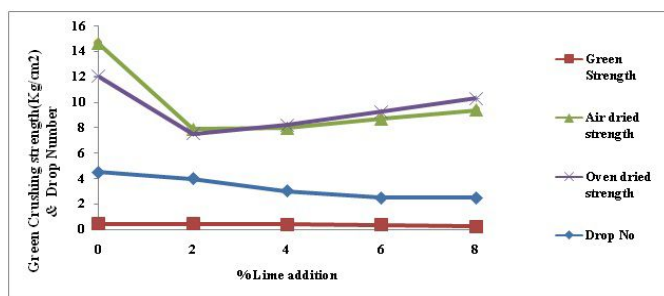

Fig 8 Strength variation of green pellets with increasing lime content

IV. CONCLUSION

Following conclusions were drawn with reference to the Blast Furnace burden.

Huge amount of lime and iron ore fines generated from mines can be utilized for making fluxed pellets which can minimize the problem of use lime stone concentrate inside the Blast Furnace

In a typical Blast Furnace burden consideration, we can calculate the maximum pellets basicity (2.37), to produced neutral slag is as low as only 8% addition(maximum) of lime fines in the pellets when use 100% high ash coke.

Increasing lime content decreased green crushing strength as compared to acid pellets due to burnt lime lime fines have the acicular/ needle like structure which retards the plasticity inside the pellets so after applying load over the pellets sudden brittle like fracture occurred without any prior deformation.

During water addition for making green pellets with burnt lime, huge steam formed inside the pellets for exothermic reaction of burnt lime with water, which creates pressure inside the pellets. When these steams tried to exit, creates pores over the surfaces which were the crack initiation area for producing crack.

But at the other hand, CaO is reacted with moisture content of pellets and formed $Ca(OH)_2$. These $Ca(OH)_2$, after further reaction with atmospheric CO_2 produced hard layer of $CaCO_3$ over the outer surface the pellets, which was responsible for further increase in strength. So increasing lime content crushing strength was also increased.

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