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Diminished Conduct of Burned Iron Ore Pellets

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Abstract*: The goal of the current project, "diminished conduct of burned iron ore pellets," is to encourage the efficient use of coal fines and iron ore in the production of sponge iron. India is currently the world leader in the production of sponge iron, and the DR-EAF route is producing more steel every day. The current project effort examined the impact of adding concentrated sucrose binder on the physical characteristics of pellets made from burned iron ore. It was discovered that the crushing strength peaked at 2% binder addition and thereafter decreased as the binder concentration increased. Porosity showed a reversal of trend, increasing as the concentration of binder rose from 1% to 8% in burned pellets. The pellets were processed for reduction experiments in various coal types after being burned at 1100 C. Up to the range under study, the degree of reduction in fired iron-ore pellets rose as the reduction temperature and time increased. It was discovered that as the coal's reactivity increased, so did the degree of reduction in burned pellets.*

Keywords: diminished conduct

I. INTRODUCTION

No matter where we are, if we take a moment to pause and concentrate, we will be able to see that different kinds and grades of steel are all around us. In fact, we find it impossible to imagine living without it. Whether it's a tiny knife used for cooking or our houses, steel is present in everything from tiny coins to enormous cars. Different kinds of steels and their preparation techniques have been produced since the time of the swordsmiths to the present day of engineering. The iron and steel sector is confident in its ability to expand quickly in the next years as India moves towards higher growth rates and more focused efforts to develop the country's manufacturing sector and infrastructure. The nation's steel demand is soaring at an 11 percent annual rate, and it is expected to stay in that range for the next 14 to 15 years at the very least. By 2017, domestic steel production capacity must exceed 140 MT annually in order to meet the nation's unrelenting need for steel. However, blast-furnace manufacturing is the main method used to produce iron. However, the development of alternative iron-making processes, such as the mini blast furnace process, smelting reduction routes, and direct reduction routes, was prompted by drawbacks associated with the blast furnace process, including: (1) dependence on high-quality metallurgical grade coke; (2) economic viability only at large capacities; (3) environmental constraints; (4) requirement of auxiliary plants; and (5) high investment and operational intensity. On the other hand, direct reduction techniques use carbon-bearing materials or hydrocarbon gases as reducing-carburizing agents to reduce iron oxides in the solid form below the fusion temperature of pure iron (1534°C). It is evident that the actual DRI can function without a gaseous medium. However, it is now widely known that indirect reduction is largely responsible for the reduction of iron oxide by carbon in blast furnaces and the direct reduction process used to produce sponge iron. The direct reduction process is currently receiving a lot of attention because, despite some drawbacks, using pre-reduced pellets or sponge iron as feed for basic oxygen furnaces, induction furnaces, and blast furnaces offers plenty of opportunity to refine coke intake productivity and economy.

Iron Ore Reserves of India

With an average iron concentration of 47%, the world's iron ore reserves are estimated to be over 170 billion tonnes. India is home to some of the world's best-quality iron ore reserves, with the sixth-largest reserves worldwide. Roughly 75% of global reserves are accounted for by India, Australia, China, Russia, and the Ukraine. As of 1.4.2010, the

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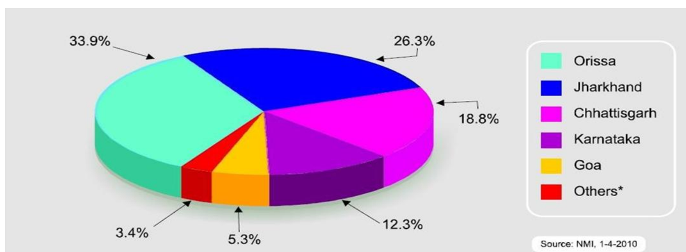
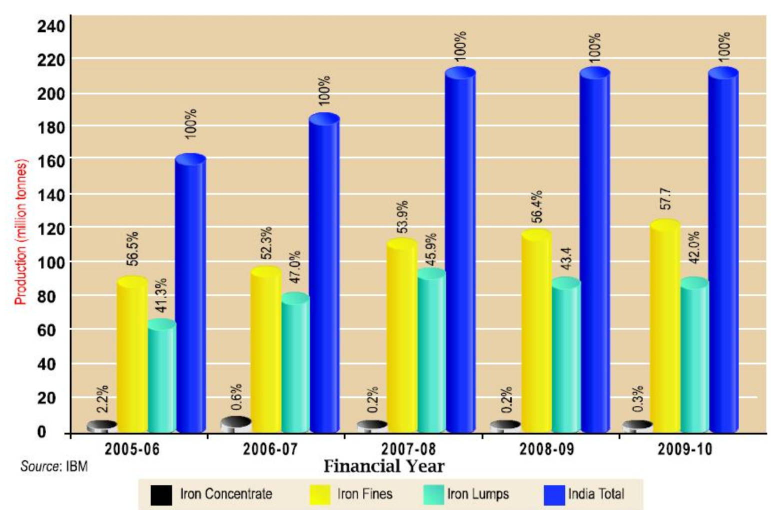
UNFC system assessed that India had 28.53 billion tonnes of iron ore reserves. The details of state-wise distribution of iron ore reserves in India are given in Table 1 & Fig-1

Mines Reporting Production :

	No. of Mines		Production (Th. Tonnes)	
	2011-12	2012-13	2011-12	2012-13(P)
INDIA	313(25)	270(14)	168582	136019
Public Sector	36	34(1)	56610	52553
Private Sector	277(25)	236(13)	111972	83466
Captive	27	27	42967	44883
Non-captive	286(25)	243(14)	125615	91136
'A' Category	137(3)	116(2)	126514	103447
'B' Category	176(22)	154(12)	42068	32572
STATES				
Andhra pradesh	40(4)	36(3)	1776	1111
Chhattisgarh	11	11	30457	27941
Goa	69(2)	43(2)	33636	10575
Jharkhand	19(1)	14(1)	19258	18010
Karnataka	67(7)	68	13233	11225
Madhya Pradesh	17(8)	14(5)	1237	1421
Maharashtra	14	11	1539	1193
Odisha	74(3)	71(3)	67414	64308
Rajasthan	2	2	32	235
GRADES				
Lumps (Total)			**62799**	**53888**
Below 55% Fe			7433	3184
55% to below 58% Fe			3184	1669
58% to below 60% Fe			2944	2725
60% to below 62% Fe			5501	3356
62% to below 65% Fe			25690	27867
65% Fe and above			18047	15087
Fines (Total)			**105383**	**81808**
Below 55% Fe			16824	8229
55% to below 58% Fe			8881	6037
58% to below 60% Fe			5993	3569
60% to below 62% Fe			19635	14869
62% to below 65% Fe			41139	35549
65% Fe and above			12911	13555
Concentrates (Total)			**400**	**323**



Statewise Total Resources of Hematite Iron Ore as on 1.4.2010



Production of Iron Ore Lumps, Fines & Concentrates in India

Figure 2 shows the comparison among production of Iron ore Fines, Lumps & Concentrate in India.

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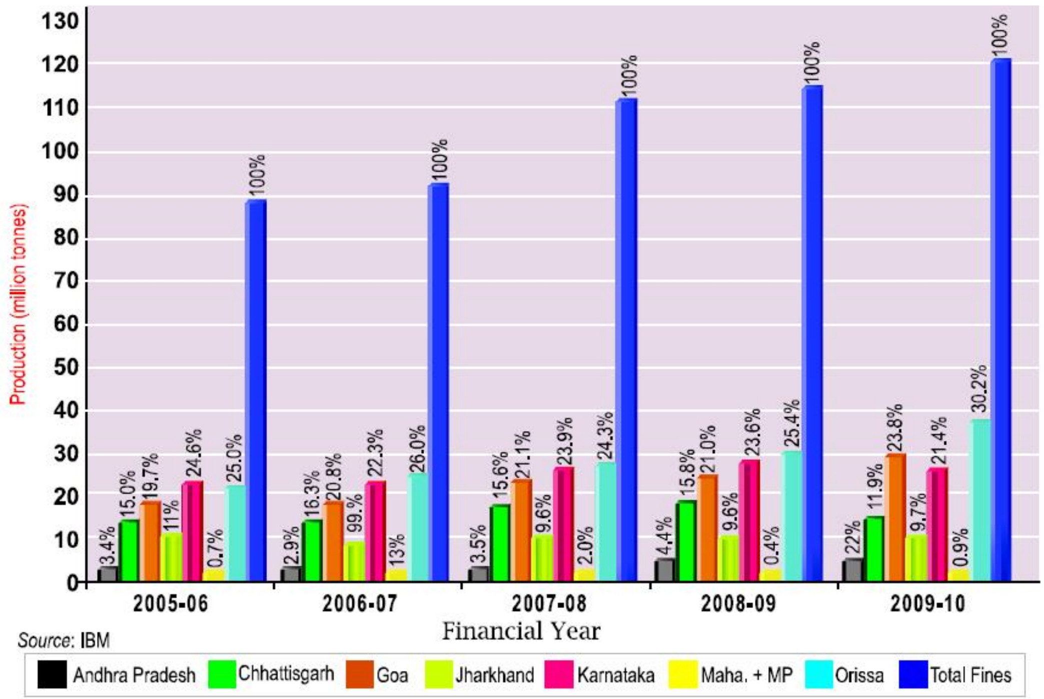

Statewise Production of Iron Ore Fines in India

Figure 3 shows the State wise Production of Iron ore Fines in India

With over 285 billion tonnes, or 10% of the global reserves, India possesses some of the world's greatest coal deposits. It possesses the world's fourth-largest coal reserves and is the third-largest producer.Coking and non-coking coal are the two main categories into which Indian coal is divided. India's non-coking coal reserves are 250895.31 million tonnes (88%), whereas its coking coal reserves are 33474.26 million tonnes (12%).India's coal reserves are spread throughout 14 states, spanning from Tamil Nadu in the south to Assam in the northeast, Madhya Pradesh and Chhattisgarh in central India, and Maharashtra in the west. However, the majority of the nation's coal-producing states are found in the eastern regions of West Bengal, Orissa, Jharkhand, etc.

Indian coal is typically used to make metallurgical coke, which is utilised in blast furnaces. Its high ash content (up to 35%) and low calorific value are essential factors to consider. In addition to its low quality, Indian coal has unfavourable washability properties. This means that removing ash without significantly reducing yield becomes challenging, even after the coal has been extensively crushed before washing. Table 2 lists the geological coal resources in India as of April 1, 2012.

Gondwana Coalfields	(In Million Tonnes)			
State	**Geological Resources of Coal**			
	Proved	**Indicated**	**Inferred**	**Total**
Andhra Pradesh	9566.61	9553.91	3034.34	22154.86
Assam	0	2.79	0	2.79
Bihar	0	0	160.00	160.00
Chhattisgarh	13987.85	33448.25	3410.05	50846.15
Jharkhand	40163.22	33609.29	6583.69	80356.20
Madhya Pradesh	9308.70	12290.65	2776.91	24376.26
Maharashtra	5667.48	3104.40	2110.21	10882.09
Orissa	25547.66	36465.97	9433.78	71447.41
Sikkim	0	58.25	42.98	101.23

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Uttar Pradesh	884.04	177.76	0	1061.80
West Bengal	12425.44	13358.24	4832.04	30615.72
Total	**117551.01**	**142069.51**	**32383.99**	**292004.51**

Tertiary Coalfields (In Million Tonnes)					
State	**Geological Resources of Coal**				
	Proved	**Indicated**	**Inferred (Exploration)**	**Inferred(Mapping)**	**Total**
Arunachal Pradesh	31.23	40.11	12.89	6.00	90.23
Assam	464.78	42.72	0.50	2.52	510.52
Meghalaya	89.04	16.51	27.58	443.35	576.48
Nagaland	8.76	0	8.60	298.05	315.41
Total	**593.81**	**99.34**	**49.57**	**749.92**	**1492.64**

Direct Reduction Procedure of Iron Making:

The DRI technique is one of the alternative methods of Iron producing with exceptional flexibility of consuming different kinds of reductants such as lower grade non-cocking coal, natural gas ,char coal, etc. Direct reduction of iron ore using a reducing gas produced from coal or natural gas produces direct reduced iron. This process yields solid sponge iron, straight reduced iron, hot briquetted iron, or iron that is 96% pure.

The various processes of DRI technique based on coal and gas are: [1]

1. Coal based rotary kiln process.
2. Gas based shaft furnace process.
3. Coal/gas based rotary hearth furnace process.
4. Multiple hearth furnace based routes.
5. Coal based DR in Tunnel kilns.
6. Fluidised bed processes.

Production Of Direct Reduced Iron In India And World

From 7.8 million tonnes 20 years ago, the total global production of DRI increased to 69.9 million tonnes in 2010. Table 5 makes it abundantly evident that the production of DRIs has grown and has been trending upward. India is now the biggest producer of DRI in the world with an output of roughly 25.34 million tonnes per annum. Roughly 19 million tonnes of the DRI generated in India in 2010 came from coal-based facilities, and the remaining 7 million tonnes came from gas-based units [8]. This significant discrepancy can be attributed to India's plentiful availability of non-coking coal and dearth of natural gas.

Production of DRI (In Million Tonnes)		
Year	**World**	**India**
2001	37.778	5.721
2002	43.18	5.732
2003	45.88	7.052
2004	53.438	9.123
2005	56.69	12.054
2006	56.376	15.031
2007	66.757	20.102
2008	66.093	20.915
2009	64.486	23.446
2010	69.951	26.307

Table 3: Year-wise production of DRI in India and World

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II. EXPERIMENTAL DETAILS

Selection of Materials

The physical and chemical properties of the haematite iron ore used in this work, which came from the Sakaruddin mines in Orissa, are described in Tables 4, 5, and 6. The study uses low grade (F) non-coking and other coal that is obtained from different mines and is analysed for its caking index (IS : 1353 1993), reactivity towards CO2 gas (IS : 12381: 1994), ash fusion temperatures (DIN : 51730 : 1984), and proximate analysis (IS; 1350: 1969). Tables 5 and 6 contain a list of the outcomes.

Table 4: Chemical composition of Fe Ore obtained from Orissa, India (wt. %, air-dried basis)

Fe (total)	Fe_2O_3	Al_2O_3	SiO_2	TiO_2	MnO	Loss on Ignition
64.53	91.4	3.09	1.51	0.17	0.03	3.57

Table 5: Physical Properties of Fe Ore obtained from mine of Orissa, India (wt. %, air-dried basis)

Tumbler Index (wt. % of +6.3mm)	Abrasion Index (wt. % of -0.5mm)	Shatter Index (wt. % of -5.0mm)	Apparent Porosity (%) Lump Ore	Apparent Porosity (%) Fired Pellets
92.79	4.82	0.59	1.5	18.7

Table 6: Mechanical properties of Iron Ore Pellets

Binder	Binder (%)	Firing Conditions		Crushing Strength (Kg/pellet)	Porosity
		Firing Temp (°C)	Firing Time(hr)		
Concentrated Organic Binder	1	1100	1	840	8.1
	2	1100	1	925	8.5
	3	1100	1	637	15.2
	4	1100	1	215	20.5
	6	1100	1	140	27.2
	8	1100	1	105	31.9

Table 7: ash fusion temperatures of non-coking coal, Chemical composition, reactivity, caking index procured from Ananta mine of Orissa, India

Proximate analysis (wt.%, dry basis)			Sulphur content (wt. %)	Reactivity (cc of CO/g. of C/sec.)	Caking index	Ash fusion temperatures(^{0}C)			
Volatile matter	Ash	Fixed carbon				IDT	ST	HT	FT
26.2	40.1	33.7	0.4	5.92	Nil	1318	1506	1602	1645

Table 8: Characteristics of coal selected (proximate analysis) in present study

Type of Coal	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Reactivity (cc of CO/g of C. sec)
Sample-A	4	27	4	65	2.9
Sample-B	3	20	7	70	3.68
Sample-C	3.5	31.5	5	60	3.05

Sample Preparation

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The iron ore fines (-100 mesh size, approximately 84%, and -16+25 mesh size, approximately 16%) were well combined with a small amount of water and concentrated sucrose binder (2%, 4%, and 6%). Pellets are then manufactured using Hand Rolling technique. The pellets are dried for more than five hours at 110 0C in an electric oven. The method used to fire the dry pellets was to place them into a muffle furnace, heat them up to 11000C at a pace of around 40C per minute, soak them there for about an hour and then cool them within the furnace.

Reduction Behaviour

Separate reductions in coal fines with a mesh size of -4+6 were done. In this study, single-type reduction experiments were conducted on the fired iron ore pellets (W e i g h t e d), which were centrally embedded inside the densely packed bed of coal particles in each of the 75 mm high by 40 mm diameter stainless steel reactors. The reactors were heated at a rate of approximately 40C/min from room temperature to the predetermined temperatures of 9500C and 10000C. Every reactor was sealed with an airtight lid featuring a vent to allow gas to escape. The temperature was kept between ± 50C. The reactors were taken out of the furnace after soaking for the prescribed amount of time, and they were allowed to cool to room temperature in the open. The reduced pellets are weighed, and the weight percentage of O2 eliminated from each one is used to calculate the degree of reduction.The diameter of the pellet is measured three times before and after reduction using Vernier callipers, and the average is used to calculate volumes. The following formula was used to determine the swelling-shrinkage at various reduction time slots:

Swelling index (%) = $\{(V_f - V_i)/V_i\} \times 100$

Where,

V_i – Initial Volume of Pellet, and

V_f – Final Volume of Pellet after reduction for a given time.

An electronic balance was used to record weight losses in pellets in order to determine the Degree of Reduction.

Degree of Reduction was calculated by following formula:

Degree of Reduction = (Weight loss in pellets / total oxygen content in the pellets) x 100

III. RESULTS AND DISCUSSION

To produce sponge iron, the oxide feed (haematite and magnetite) often needs to include more iron than 62%, and the maximum amount of silica plus alumina allowed is 4% (Table 9). Iron ores containing more than 66% Fe are difficult to reduce, and more FeO is retained in the generated DRI. Conversely, lower grade ores (with a Fe concentration of 62–66%) are probably more suited for the production of sponge iron. A reduced degree of metallisation in the reduced product could result from a higher (TiO2) content, which could negatively impact the oxide feed's reducibility. Table 6 states that the oxide feed's (TiO2) level should generally not be higher than 0.15%. High reactivity coals are often preferred because they enable kiln operations at relatively lower temperatures with better productivity and a reduced propensity for ring-formation.The main deformation temperature (IDT) of coal's ash is another crucial feature. The coal's caking index should ideally be less than 1 (but up to 3 is acceptable) to guarantee that there is no agglomeration development in the charge bed. However, this coal's higher ash content and lower fixed carbon content might make it more necessary to use in rotary kilns for the manufacturing of DRI.

Reduction Behaviour of Fired Fe Ore Pellets

Figures 6 and 7 below provide the data on the degree of reduction vs time (Table 11) for burnt iron ore pellets reduced in sample A, B, and C coal (size: -4+6 mesh size) at temperatures of 950 and 1000 C.

Binder	**Binder (%)**	**Reduction Temp (°C)**	**Coal Type**	**Time (min)**	**Degree of Reduction (%)**
			Sample A	5	42.4
				10	51.7
				15	69.8
			Sample B	10	43
				15	58.05

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Concentrated Sucrose binder	2	950	Sample C	10	41.5
				15	56.46
		1000	Sample A	5	61.2
				10	77.33
				15	84.99
			Sample B	5	23.8
				10	40.57
				15	40.57
			Sample C	5	12.21
				10	34.18
				15	47.03

Table 9: Reduction Characteristics of Fired Iron Ore Pellets

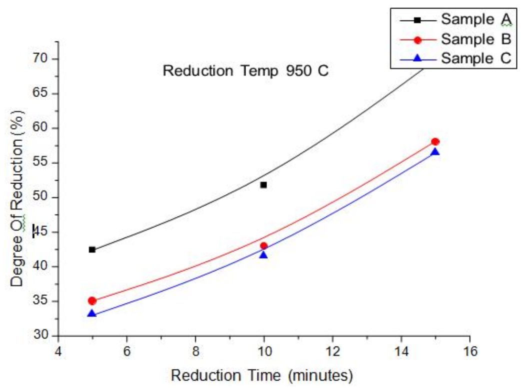

Figure 6: Degree of Reduction vs. Time graphs for the reduction of fired Fe Ore Pellets fired at 1100^{0}C and reduced in coal (-4+6 mesh size) at a temperature of 950^{0}C.

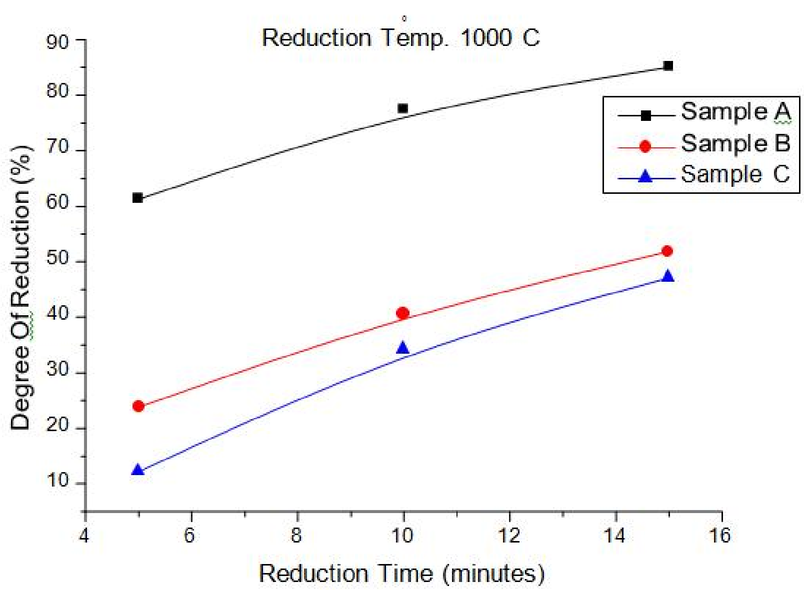

Figure 7: Degree of Reduction vs. Time graphs for the reduction of fired Fe Ore Pellets fired at 1100^{0}C and reduced in coal (-4+6 mesh size) at a temperature of 1000^{0}C

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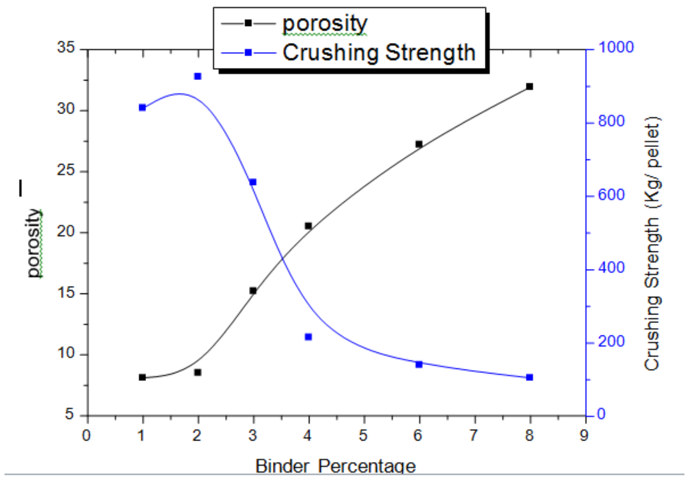
The findings (figures 6 and 7) demonstrate that, in every study involving burnt iron ore pellets, the reduction rate considerably increased when the temperature rose to 9500C or 10,000C. This figure illustrates how, at all the examined temps, the degree of decline likewise increases with time.

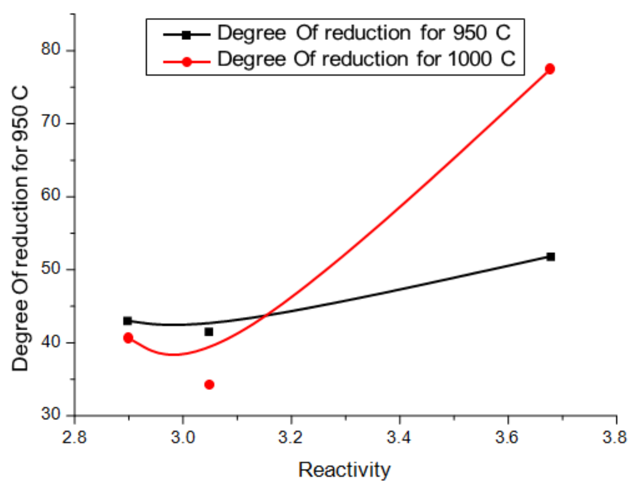


Effect of Binder %:-

Figure 8 illustrates how the trials reveal that crushing strength reduces as binder percentage increases. Figure 8: Crushing strength and porosity versus binder percentage

Effect of Coal Reactivity:-

Additionally, the trials show that the reactivity of the coal—which is graphically represented in figure 9—determines the level of reduction.



Effect of Coal Chemistry:-

Figure 10 shows the variation of degree of reduction with respect to Volatile matter content.

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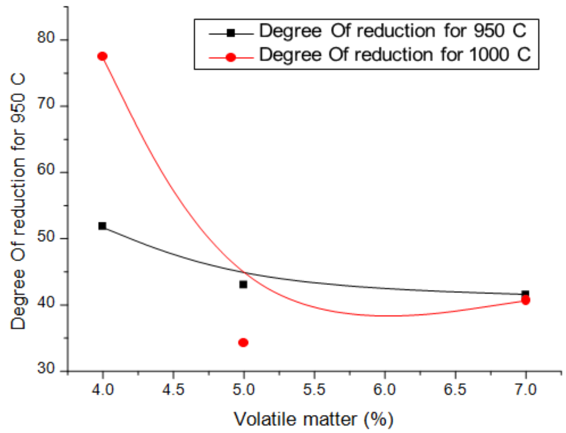

IV. RESULTS AND DISCUSSION

When concentrated organic binder is added, the burned Fe-ore pellets' crushing strength decreases from 2% to 8%.
Adding concentrated organic binder increases the porosity of the burned Fe-ore pellets from 2% to 8%.
In the temperature range under study (950–10,000C), the degree of reduction increases as temperature increases.
Up to the range under study, the degree of pellet reduction rises as reduction time increases.
When the reactivity of the coal increased, so did the degree of reduction of the burnt Fe-ore pellets.
There was increase in reduction % of the burnt iron ore pellets with rise in reduction time.

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