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Study of SFCA and SFCA-I Phase in the Ternary Phase System of Iron Ore Pellets

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Abstract— ***To get an effective makeover of available low-grade iron ore, the selection of additive with fixed composition is the key variable. Pellets thermal stability and effective reduction depend upon mineralogy, physio chemical characteristics which are governed by the basicity of pellets up to a certain extent. Basicity varies with gangue content present in the iron ore. Therefore to ascertain physio chemical characteristics, a deeper insight analysis is done, microstructure phase study within silico-ferrite of calcium and aluminium (SFCA) system was done. Phase relation of the intermediate phase is calcium ferrite formation which reacts further to form SFCA and SFCA-I. The Physio-chemical and physical properties especially strength is supported by SFCA-I. The grade of ore is also being the base of SFCA or SFCA-I. The ternary phase study gives an overview of the phase relation and thermal and compositional conditions for the formation of SFC phases. In the present study, SFCA/SFCA-I formation during firing at 12500C with pellets of varying basicity, 0.2-1.2 has been observed. The influence of the formation of SFCA/SFCA-I over physical properties is also considered and 0.6 basicity exhibits good pellet quality***

Keywords: Ternary phase; SFCA; SFCA-I; CCS; Apparent Porosity; Basicity

I. INTRODUCTION

Indian iron ore can be categorized into three-class as a superior class (>65% Fe), medium class (<65 and >62% Fe) and inferior class (<62% Fe) concerning iron oxides present [1]. With the threat of superior grade ore exhaust, medium and inferior grade iron ore is being used as a second choice. This grade iron ore requires makeup to level up to match minimum industrial parameters due to high gangue content and low Fe present in the inferior grade, as well as concentration their beneficiation is also required. Moreover to prepare raw material for blast furnace pelletization is the very important step in which raw ore fines are used to make balls of optimum chemistry as basicity, strength, porosity and reducibility, etc. [2].The feedstock of the blast furnace of required quality parameters is prepared by keeping into consideration so many input variables such as fineness their chemical ingredient moisture, heat hardening with optimum temperature, etc. In the present study, physic-chemical properties of pellets along with physical strength are considered, for which intermediate phase formation during heating of pellets is considered. The flux pellets formation for industrial use is in the trend hence basicity of pellets is imperative [3].To get a good quality of pellets to depend upon supportive crystallography and microstructure formation with optimal ore characteristics with the thermal condition [4].

II. PELLET MAKING

The surface tension of water & gravitational force creates pressure on particles, so they coalesce together & form nuclei that grow in size into a ball. After green ball formation heat hardening is preceded in the RHF (raising hearth furnace). Pellets were fired at 1250^{0}C during its induration cycle.

III. TERNARY PHASE DIAGRAM

During heating different phases are formed at high temperatures, based on ore chemistry and natural characteristics. In the ternary phase diagram Fe_2O_3–Al_2O_3–CaO–SiO_2 (FACS) and Fe_2O_3–CaO–SiO_2 (FCS) systems have opted through experiments to get phase determination.

This is going to illustrate the iron ore behaviour at different heating cycles as per physical and chemical characteristics. Physical and metallurgical characteristics of indurated pellets depend upon bonding phase chemistry. The study shows the low-grade iron ore form SFCA of bonding phase while mid-range of iron forms both types of compound SFCA and SFCA-I, instead of a mixture, high-grade ore form SFCA-I only significant amount [5-6]. For the better physical strength and reducibility property, SFCA-I is the most desirable phase compound in the pellet microstructure as shown in Fig.1.

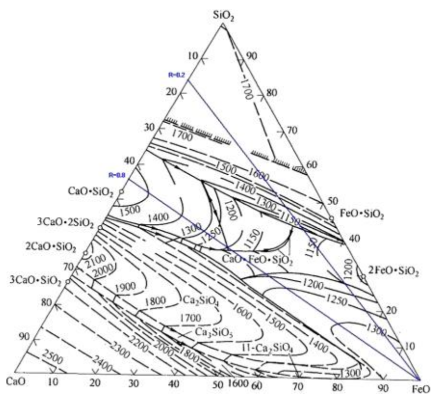

Figure.1

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This shows the phase occurrence at a particular temperature with the composition ratio of CaO, SiO, and FeO on the three sides of the triangle or ternary axis with phase [7].

IV. METHODOLOGY

Noamundi Indian mines ore had been collected for the study which was found as dumped fines (-10mm). For the preparation of 200 mesh grains size balls ore has been processed.

To prepare six different samples with variable basicity from 0.2 as shown in Table 1.

Table 1

Sample	Pellet A	Pellet B	Pellet C	Pellet D	PelletE	PelletF
Basicity	0.2	0.4	0.6	0.8	1	1.2
CaO	14.75	7.37	4.95	3.68	2.95	2.45

Wet Ball Making: For making iron ore balls, the ore mixture is prepared with some additives homogenously. The dick pelletizer is used to get green balls of diameter range from 8-18 mm and moisture 8-10% by volume is maintained. Heat hardening of green pellets had been done in the furnace to get sintering of pellet and get physical strength of order at least 2.5 KN desirable in industries. Fired pellets are shown in Fig. 2.

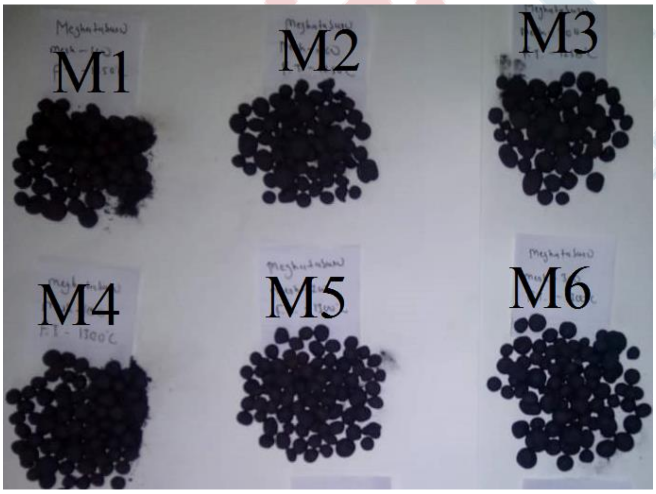

Figure. 2

V. PELLET CHARACTERIZATION

For the pellets characterization, pellets were rubbed by emery paper of grit size vary from 200 to 1200. This grinding is followed by diamond polishing to get SEM images of pellets microstructure. To identify various phases present in the microstructure in the polished section of pellets grey scaling is done to notify hematite, magnetite, silicate and porosity. The grey phase represents hematite, pinkish grey for magnetite, dark grey for silicate phase and black for porous phases [8-9].

This is surprising since the levels of Fe, SiO_2, Al_2O_3, P, MgO and other elements, together with the nature of the minerals in the fine ore, are believed to play a key role in determining the abundance and type of high-temperature bonding phases. SFCA is a key bonding phase in fluxed basic iron ore pellets. Pellets properties depend on microstructure characterization and crystal formation and crystal transformation at different thermal and material conditions.

Phase Analysis:

The Image-J tool was used to analyze the optical images for the various grains of phases, their area, and grain density. The procedure of image analysis elaborated as follows with the

VI. RESULT AND DISCUSSION

Cold Compressive Strength: The cold compression strength is a measure of the capacity of sustaining under the burden load-tested data presented as in Table 2

Table 2

Sample	Basicity	CaO	CCS(KN)
Pellet M1	0.2	14.75	3.2
Pellet M2	0.4	7.37	4.1
Pellet M3	0.6	4.95	7
Pellet M4	0.8	3.68	5
Pellet M5	1	2.95	4.8
Pellet M6	1.2	2.45	2.4

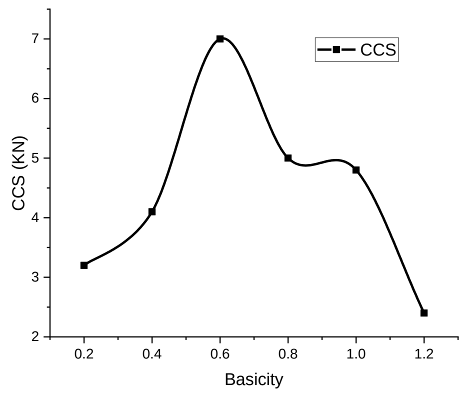

Fig. 3 Basicity vs. CCS

Fig. 3 shows the variation of CCS first increasing from 3.2 KN to 7 KN then reduced to 2.4 KN corresponding to the basicity of pellet. Maximum CCS is obtained at 0.6 basicity when the pellet is dried fully and offer maximum CCS.

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Grain Density:

Fig. 4 shows the hematite grain density and the highest 311 grains / mm^2 were attained at a basicity of 1.2. The grain density at basicity of 0.4 was 359 grains / mm^2. Good quality of ore has high grain density as 878 grains / mm^2 at basicity of 0.6 where we get high CCS value. At basicity of 0.8 then it decreases to 721 grains / mm^2. , after basicity of 0.6 the hematite grain density going to decrease from 878 grains / mm^2 to 311 grains / mm^2 concerning basicity of 0.6 to 1.2.

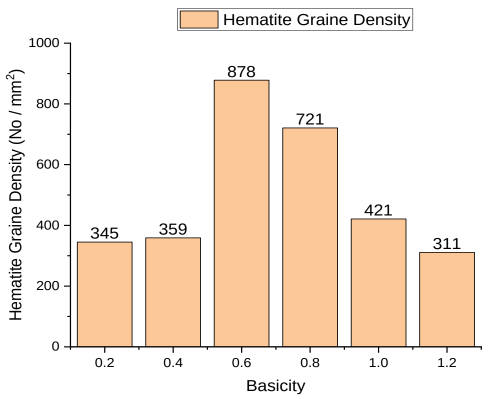

Fig. 4 Basicity vs. Hematite grains density

Fig. 5 shows pore grain density (PGD) at basicity of 1.2 was 342 grains / mm^2 causes the lower strength due to the highest porosity. PGD at basicity of 0.4 was 221 grains / mm^2 may be due to the formation of some other phases. PGD 148 grains / mm^2 is the least at basicity of 0.8 hence pellet has 5KN CCS at this basicity. After that, the pore grains density is increased from 148 grains / mm^2 to 342 grains / mm^2 on increasing the basicity from 0.8 to 1.2.

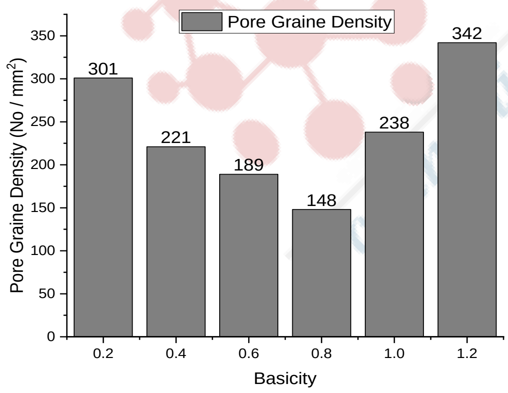

Fig. 5 Basicity vs. Pore grains density

The magnetic grain density (MGD) 121 grains / mm^2 minimum value at basicity of 0.4. MGD 125 grains / mm^2 is the intermediate value at basicity of 1.0. MGD 212 grains / mm^2 was highest at a basicity of 0.6 at which we got the highest CCS value.

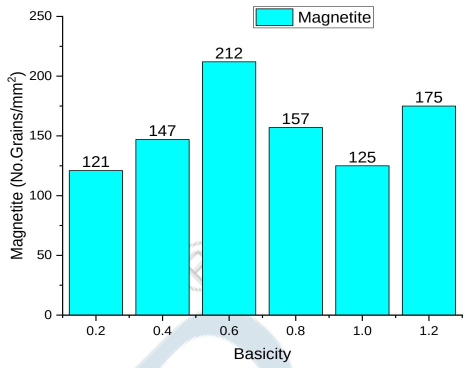

Fig. 6 Basicity vs. Magnetite grains density

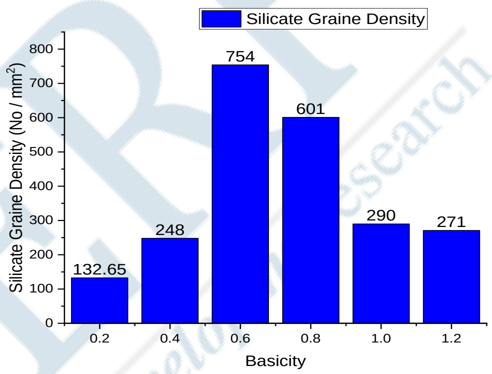

Fig. 7 Basicity vs. Silicate grains density

The magnetic phase grain density is 125 grains / mm^2 were at basicity of 1.0 and increasing to 175 grains / mm^2 at basicity of 1.2 as shown in Fig. 6.

The silicate grain density (SGD) was 132.65 grains / mm^2 minimum at the lowest basicity of 0.2 and then it increases to 754 grains / mm^2 at a basicity of 0.6 where we got the highest value of CCS. SGD 754 grains / mm^2were the highest at basicity of 0.6. After that, the silicate grain density was decreased from 754 grains / mm2 to 271 grains / mm^2on increasing the basicity from 0.6 to 1.2 as shown in Fig. 7.

Basicity versus all phases grains density

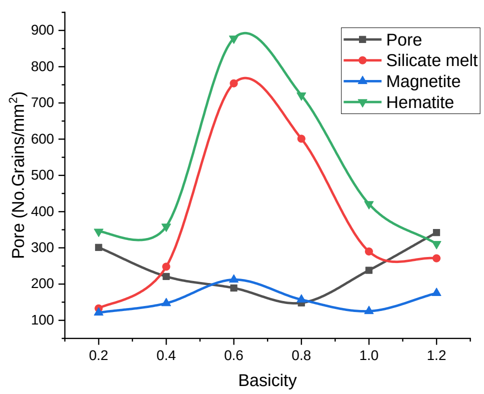

Fig. 8 Basicity vs. grain density

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In Fig. 8 SGD increase with basicity rises the maximum value of SGD 754 grains / mm^2 corresponding to basicity 0.6. But for basicity 0.8 least PGD 148 grains / mm^2 respective of HGD 721 grains / mm^2 with MGD 157 grains / mm^2 minimal due to oxidation of iron oxides at this temperature. After basicity 0.6 the hematite phases grain density decrease continuously. The pore phase grain density decreases as the basicity increase from 0.2 to 0.8. and silicate phase grain density increases as basicity increases from 0.2 to 0.6.

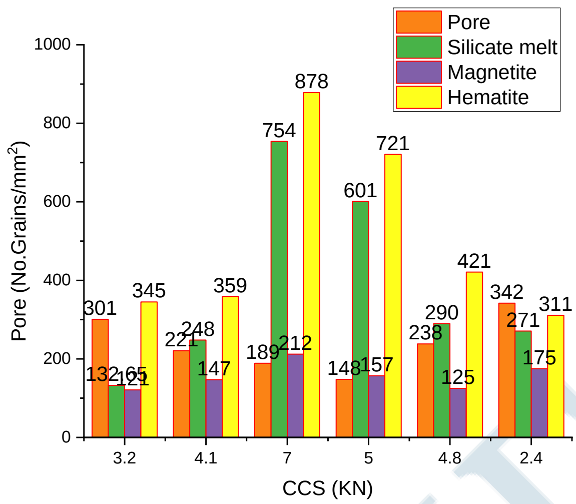

Fig. 9 CCS vs. Phases grains density

In Fig.9, as basicity from 0.2 to 0.6 increases, PGD increases. Then going down with respective basicity 0.8. This can be observed a combination of hematite and silicate phases decide the strength of pellets and a combination of the pore and magnetite phase reduces the pellets bonding and finally weakened the structure. The highest CCS is obtained at a basicity of 0.6 is 7 KN because of a greater amount of hematite phase grain density. The lowest value of CCS is obtained at a basicity of 1.2 is 2.4 KN because of a large amount of pore phase grain density. As we have seen that on increasing the hematite phase grain density and silicate phase grain density the CCS value also increases. On increasing the pore phase grain density the CCS value is decreased [13-16].

Ternary phase diagram: The pellet composition lies within the $Fe_2O_3(–Fe_3O_4)–CaO–SiO_2$ ternary phase system where various intermediate phases($Ca_2Fe_2O_5$ (C_2F) or $CaFe_2O_4$ (CF)) are formed as calcium ferrite bonding phases. Then these intermediate phases are transformed into microstructure phases like SFCA and SFCA-I the low-grade iron ore form the SFCA of bonding phase while mid-range of iron forms both types of compound SFCA and SFCA-I, instead of the mixture, high-grade ore form SFCA-I only insignificant amount [5]. For the better physical strength and reducibility property, SFCA-I is the most desirable phase compound in the pellet microstructure. Generally 'SFCA-I' has platy morphology and SFCA has prismatic morphology in the microstructure. SFCA and SFCA-I phases are mapped on the ternary diagram with the interpretation of the present amount of SiO_2, CaO and Fe as shown in Fig. 10.SFCA-I phase exhibits good physical strength.

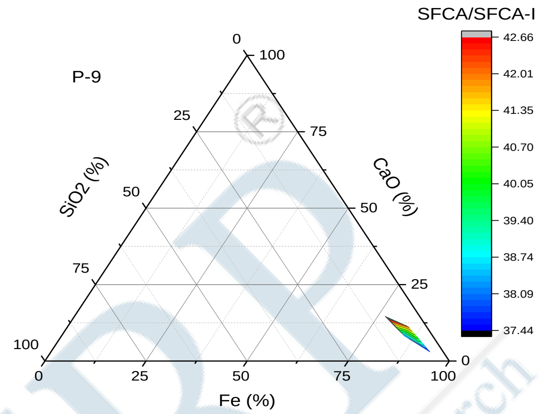

Fig. 10 Ternary phase of $Fe_2O_3(–Fe_3O_4)–CaO–SiO_2$ representation.

In this Fig.11, an ideal representation of SFCA and SFCA-I phases are shown on a ternary plane of the FCS system, in which iron ore-rich corner shows SFCA phase stability and CaO and SiO_2 variation shows the CF formation and transformation to SFCA.

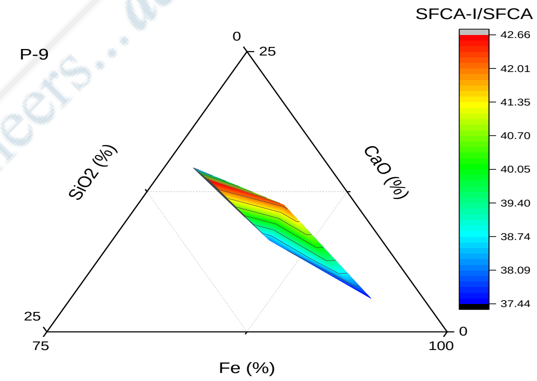

Fig.11 Ternary phase of $Fe_2O_3(–Fe_3O_4)–CaO–SiO_2$ (Large) representation.

This shows the clear pictorial view of the SFCA phase stability as per Fe, SiO_2, CaO composition ingredients. In this study, CCS of pellets depends upon the bonding phase SFCA formation its transformation to SFCA-I which shows higher intensity at rich Fe corner and minimal alumina and silica [10-11].

The actual FCS representation is shown in Fig.12 where the iron corner depicts the maximum 75% iron content and 0-35% of CaO and $A_{12}O_3$. The black dot point shows each configuration of the composition of silica, alumina, iron on a ternary plane is shown. Where silicate (SFCA) dots are located as per the configuration of these three ingredients. The maximum CCS is obtained at 4.95 calcium oxide at the iron-rich corner of the ternary diagram which shows that the high-intensity of SFCA transforms to SFCA-I [12-16]. The minimum CCS obtained where SFCA has the lowest density obtained at 2.94 calcium oxide away from iron corner satisfy the theoretical concept as illustrated in Fig.13.

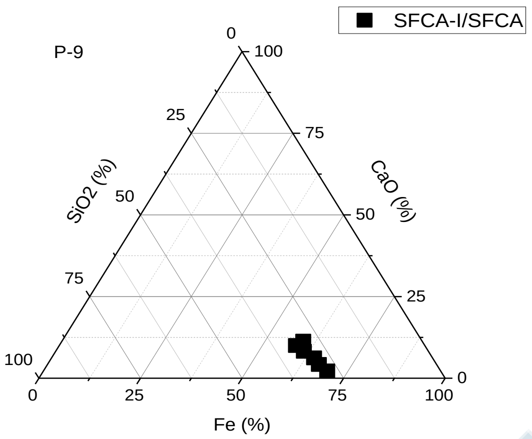

Fig.13 Ternary phase of Fe_2O_3 ($-Fe_3O_4$)$-CaO-SiO_2$ (ACTUAL) representation

VII. 7. CONCLUSION

The key findings of the study are as follow.

1. For the period strength basicity play an important role where optimum basicity is 0.6 gives the maximum strength to the pellets 7 KN, while lower basicity and higher basicity does not promote the pellet strength.
2. The addition of flux as lime will also support pellet strength as for the optimum value 4.95 calcium oxide provide the highest pellet strength. The calcium oxide takes part in the formation of phase bonding which is the base of strengthening the pellet structure.
3. The strength of the pellet depends on intermediate phase formation such as calcium ferrite and silico-ferrite, the silicate phase and hematite grain density strongly impart the strength to pellet structure. For highest CCS pellet has maximum silicate and hematite phase density.
4. The ternary phase diagram represents the possibility of formation of silico-ferrite of calcium and alumina (SFCA), with the percentage of CaO 0-5% and SiO2 1-6% insertion in the pellet mix.
5. The robust pellet structure is formed when SFCA-I phase bonding is achieved which contain the highest iron oxide and optimal CaO and SiO2.
6. Formation of SFCA-I intended to form in the region of Fe more than 75% content.

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