Effect of Variation of Alumina on the Microhardness of Iron Ore Sinter Phases

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1. Introduction

The productivity of blast furnace can be increased if a higher proportion of sinter is charged. Since the Indian sinter has higher amount of alumina (~2.5%) in comparison to sinter produced elsewhere (Al$_2$O$_3$ less than 2%), the proportion of sinter in the blast furnace burden cannot be exceeded beyond certain limit. Alumina also decreases the sinter quality in terms of its chemistry.

A higher amount of alumina can be tolerated without significant reduction in strength, if the amount of FeO is high in sinter. This increases the coke rate during sintering and in the blast furnace.

The properties of melts formed in the flame front during iron ore sintering determine the structure of the ensuing sinter bonding phases. The study showed that phosphorus, silica, alumina and magnesia levels, sinter basicity and maximum sintering temperature influenced bonding phase structure.\(^2\)

Ferrites are one of the important phases in sinter. Most existing calcium ferrite in sinter has been identified as a solid solution of CaO·2Fe$_2$O$_3$·(CF$_2$) with small amounts of dissolved Al$_2$O$_3$ and SiO$_2$, known as SFCA (silicoferrite of calcium and aluminium). The SFCA is the major bonding phase in iron ore sinter and has been extensively studied on account of its important role in influencing key sinter-quality parameters such as mechanical strength, reducibility and reduction degradation. The SFCA can be divided on the basis of composition and morphology into two main types: one is a low-Fe form of SFCA, is simply referred to as SFCA, and the second is a high-Fe, low-Si form called SFCA-I. The SFCA-I has a characteristic "platy" morphology, although it may sometimes appear needlelike or acicular in cross section. In contrast, SFCA is reported to exhibit a prismatic form, and its morphology has often been referred to as columnar, blocky, or lath shaped.\(^3\)

Pownceby and Clout\(^1\) observed that the phase relationship is dependent on thermal and compositional parameters and the bonding phase chemistry affects the physical characteristics.

They also concluded that:

- Low grade ores (<62% Fe) leads to formation of SFCA (mainly).
- The Medium grade ores (62–65% Fe) leads to formation of both SFCA and SFCA-I.
- High grade ores (65–68% Fe) leads to formation of SFCA-I (mainly).

SFCA-I is the most desirable phase in iron ore sinter since microstructures composed entirely of this phase show higher physical strength and higher reducibility than microstructures composed predominantly of SFCA.

The typical temperatures used in sintering (1270–1300°C) favours the formation of both SFCA and SFCA-I. However heating above 1300°C the destruction of SFCA-I and formation of SFCA takes place.

The adverse role of alumina in the sinter on its strength and the so-called reduction-degradation index (RDI) is a known fact. Any increase in alumina content of the sinter beyond 2 wt% decreases the sinter strength.\(^5\) It increases the RDI, and as a result, coke rate goes up. For maintaining the same RDI with increased alumina content, amount of flux has to be increased, that leads to various problems in blast furnace.

It is evident that the alumina has an important role in shaping the sinter microstructure which in turn will affect the sinter strength and quality. Furthermore Indian iron ores are high in alumina, thus, investigation of the role of alumina for ensuring the sinter strength is the need of the day.

2. Experimental

2.1. Pot Sintering Experiments

Sinter samples of varying Alumina and CaO levels were generated in sinter pot. The bed height was kept 60 cm, ignition hood temp. 8°C, 1100, and suction (mm/WC) 1300. The raw material proportions in base mix were as: iron ore 70 mass%, limestone 8%, lime 3%, pyroxenite 1.5%, serpentine 2%, return fines 10%, coke breeze 5.5%. The tumbler index (TI) was measured as per the Indian Standard, IS 6495. The measurement method for RDI is JIS M8720.

2.2. Microstructural Investigations

Mineralogical study of the sinters was carried out with the help of reflected light optical microscope (Carl zeiss, Axiosplan 2 imaging). Average of 100 fields per pot test, were studied in the microscope. The quantification was done by using the image analyser software axioplan 4.3.

2.3. Indentation Studies

Microhardness testing was done by microhardness testing instrument and is reported as standard Vickers hardness number (HV). Polished sinter samples were used for this study. The microhardness tester used in this study was Leitz miniload-2. Standard indentation procedures were employed throughout and a load of 981 mN was used for all the phases. The indentation time was kept constant at 15 s. The Microhardness was determined based on the average of 30 data points for each phase.

3. Results and Discussion

3.1. Chemical Analysis of the Sinter

Table 1 shows the composition, strength and RDI of eight different sinters chosen for microstructural investigation. The Al$_2$O$_3$ content of the sinters varied in the range of 1.4 to 2.5%.
3.2. Qualitative and Quantitative Investigation of the Mineralogical Phases

The sinters shown in Table 1 were studied for their mineralogical characteristics with the help of optical microscope and image analyzer. The mineralogical phases present in different sinters are shown in Table 2.

The quantification of sinter phases show a wide variation in hematite phase (5–12%), magnetite (27–43%), SFCA (39–60%) and silicate phase (1–18%).

3.3. Micro-hardness Investigation of Mineralogical Phases

The sinter samples shown in Table 1 were analysed for micro-hardness of different phases. The micro-hardness analysis of the sinter phases shows a wide variation with respect to sinter chemistry and strength (Table 3).

The adverse effect of high Al₂O₃ on micro-hardness of hematite and magnetite phases is noticeable. Strained lattices of hematite and magnetite are more prone to degradation esp. during reduction.

The micro-hardness of the phases shows an increasing trend with increase in sinter Al₂O₃ level (Figs. 1, 2, 3).

There is a possibility that the Al exists in the lattice of hematite and magnetite phase, unlike Al₂O₃ as a bond in SFCA phase, thus causing strain in the lattice which is reflected in the increase of the micro-hardness of the phases. This may be one of the reasons for the increase in the

| Sample no. | T_Fe% | CaO% | SiO₂% | MgO% | Al₂O₃% | FeO% | P% | T.I. | R.D.1  |
|------------|-------|------|-------|------|--------|------|----|-----|-------|
| 1          | 60.69 | 6.9  | 4.44  | 1.56 | 1.4    | 10.87| 0.07| 61.93| 39.90 |
| 2          | 60.03 | 6.9  | 4.62  | 1.65 | 1.7    | 11.70| 0.09| 64.00| 29.70 |
| 3          | 59.70 | 7.4  | 4.81  | 1.45 | 1.5    | 7.90 | 0.06| 62.13| 28.60 |
| 4          | 59.90 | 7.4  | 4.27  | 1.46 | 2.3    | 8.03 | 0.10| 65.20| 33.30 |
| 5          | 58.13 | 7.8  | 5.30  | 1.70 | 2.5    | 10.39| 0.11| 61.50| 35.30 |
| 6          | 59.25 | 7.8  | 4.66  | 1.38 | 1.7    | 7.52 | 0.09| 67.53| 35.10 |
| 7          | 61.07 | 8.7  | 3.08  | 0.38 | 1.9    | 16.10| 0.09| 70.00| 33.80 |
| 8          | 57.73 | 9.7  | 4.32  | 1.57 | 2.2    | 9.92 | 0.11| 72.90| 29.80 |

| Area Phase percent |
|--------------------|
| Sample no. | Hematite% | Magnetite% | SFCA% | Silicates% |
| 1          | 12        | 26         | 53    | 7         |
| 2          | 5         | 32         | 45    | 18        |
| 3          | 11        | 29         | 46    | 15        |
| 4          | 10        | 32         | 53    | 5         |
| 5          | 9         | 29         | 52    | 10        |
| 6          | 3         | 43         | 39    | 15        |
| 7          | 12        | 27         | 60    | 1         |
| 8          | 6         | 31         | 55    | 8         |

| Microhardness in HV (the range of Microhardness is given in brackets) |
|-----------------|
| Sample no. | Hematite (HV)| SFCA (HV) | Magnetite (HV) |
| 1          | 863 (525-988) | 801 (665-974) | 586 (519-715) |
| 2          | 873 (802-988) | 853 (689-933) | 713 (665-782) |
| 3          | 866 (782-974) | 625 (488-933) | 536 (397-657) |
| 4          | 921 (536-1048) | 770 (724-974) | 721 (542-858) |
| 5          | 1042 (882-1246) | 774 (454-870) | 716 (385-813) |
| 6          | 864 (724-974) | 642 (566-698) | 594 (529-782) |
| 7          | 1043 (588-1206) | 698 (473-882) | 737 (579-870) |
| 8          | 913 (627-1132) | 699 (508-802) | 706 (612-846) |
strength of the sinters. On the other hand the increase in MgO in sinter increases the microhardness of SFCA (Fig. 4) which is not desirable.

The average micro-hardness of the tested sinters was calculated from the average microhardness of the individual phases (from Table 3) and their corresponding area fractions in the sinter (from Table 2).

The average microhardness is observed to be related with the sinter strength. There is an improvement in TI with decrease in microhardness, which is desirable (Fig. 5).

4. Conclusions

Based on the study, the following conclusions are made:

(1) In general hardness is a measure of the resistance to deformation. Higher microhardness means poor fracture toughness (ductility) of phases. The average microhardness is observed to be related with the sinter strength. There is an improvement in TI with decrease in microhardness, which is desirable.

(2) Al₂O₃ has a predominant effect on the microhardness of Hematite and magnetite phases. Microhardness of these phases increase sharply above 2% alumina in sinter. This may be attributed to higher strain in lattices caused by Al atom entrapment in the lattice structure. This can result in rapid crack propagation and weakening of the phase’s.

(3) Higher CaO and low MgO levels in sinter are favourable for lowering the microhardness of SFCA phase.

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