Mineralogical Constraints on Beneficiation of Low-grade Iron Ores: Case Studies from Jharkhand and Goa

B. Nayak*, Damayanthi Sri and Mamta Sharma

Mineral Processing Division, CSIR National Metallurgical Laboratory,

Jamshedpur – 831007, INDIA

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Abstract

Due to increasing demand of iron ores in India, much emphasis is given on beneficiating low-grade iron ores with a cut-off of +52% Fe instead of the traditional cut-off grade of +58% Fe. In such an attempt we have characterized bulk low-grade iron ores from two different sectors namely, Gua area in the state of Jharkhand and iron ore mines from southern Goa. An integrated instrumental method of characterization using optical microscope (OM), scanning electron microscope (SEM, +EDAX), and X-ray diffraction (XRD) reveal that while the Goan low-grade ores are mineralogically simple consisting primarily of martite and quartz, the ores from Jharkhand are complex consisting of hematite, goethite, clay, quartz, and gibbsite. The tenor/grade of the Goan ore is much less (~43% Fe) compared to the ore of Jharkhand which contains ~54% Fe. Alumina (Al_2O_3) which is the main problem in the low-grade ores of Jarkhand or generally in Eastern India is found to occur associated with clay, gibbsite and as adsorption in goethite. Textural evidences indicate that while it may be possible to remove these gangue phases from the inter-granular pore spaces it will be quite difficult to liberate the intra-granular impurities that are bound within hematite and goethite in micron levels. On the contrary, these problems do not occur in the studied Goan ores where the iron-bearing phases are not chemically contaminated and are liberated well by comminution. These mineralogical studies indicate that though the Goan ores are low in Fe content, these can be beneficiated to get a higher grade (+63% Fe) with a high recovery while it will be difficult to improve the Jharkhand ores to similar grade with higher yield.

*Corresponding author: B. Nayak, E-Mail: brn69@rediffmail.com , Ph. No. +91-657-2349002.

1. Introduction

The demand for iron ore is increasing day by day and the high-grade ores are depleting at a faster rate [1,2]. The scarcity of high-grade ore (cut-off +58% Fe) is compelling the iron and steel industries to look for low-grade ores and beneficiate them to meet their requirements. However, the use of such low-grade ores has not yet picked up pace in India. This is primarily because of (i) still availability of high-grade ores, (ii) alumina content of the low-grade ores, (iii) cost investment in the beneficiation plants. Nevertheless, the Govt. of India, through its National Laboratories, is keen to develop beneficiation processes for the low-grade ores including BHJ/BHQ. In such an attempt during the current five year plan a project is being pursued at the CSIR National Metallurgical Laboratory, Jamshedpur to address the above challenges. Under this project, BHJ/BHQ, dump fines, slimes and low-grade ores from different sectors are being investigated to develop efficient beneficiation flow-sheets. These samples have been characterized with respect to their mineralogical, textural and liberation characteristics in order to provide necessary inputs for various unit operations in the process flow-sheet. In this paper we present the findings on how the mineralogy (not only the chemistry) of the ore shall have the control while developing a flow-sheet and its bearing on the ultimate beneficiation products.

2. Materials and Methods

Bulk quantity of low-grade iron ores in form of ROM were collected from two different mines; one from the Gua Ore Mines of Steel Authority of India Limited and the other from Fomento Resources in southern Goa. The ores were crushed to below 30 mm size. Following conventional coning and quartering method representative samples were prepared. From the representative samples, secondary samples were drawn for petro-mineralogical studies, liberation characteristics and chemical analysis. An integrated instrumental method of characterization using optical microscope (OM), zoom stereomicroscope, scanning electron microscope (SEM, +EDAX), and X-ray diffraction (XRD) was used to characterize the ore. Polished mounts of both lumps and fines were prepared using epoxy resin and were studied under polarized reflected light using Leica-make optical petrological microscope and under scanning electron microscope (SEM, HITACHI S-3400N). Composition of the phases were determined by EDAX (thermoelectron NSS-300) attached to the SEM. X-ray image maps for elemental mapping was carried out wherever felt necessary. Powder samples were investigated by X-ray diffraction using a Seifert X-ray diffractometer (model: XRD 3003 PTS) with Cu-target. Liberation of the minerals in fine size-classes was found out by manual modal-grain counting method using a zoom stereo microscope (Leica-Wild M8). Weight chemical analysis was carried out with respect to total Fe, SiO_2 and Al_2O_3 by conventional gravimetric method. Loss on ignition (LOI) at 900 °C was also determined.

3. Results and Discussions

The low-grade ores from south Goa analysed 43.71 wt% of total Fe, 2.59% Al_2O_3, 29.48% SiO_2 and 3.49% LOI. The ore is mineralogically simple consisting primarily of hematite and quartz (Fig 1). The hematite phase in this ore is of secondary origin and is the product of oxidation of original magnetite and is called martite. Both martite-hematite and quartz occur in well crystalline form in the size ranges of 50 to 250 μm. Occasionally, goethite and very rarely traces of clay are recorded. This simple mineralogy, texture and close size range of the grains indicate a good liberation behavior of the ore and the same was observed under a zoom stereo microscope. When crushed, both quartz and hematite are well liberated and can be separated easily using conventional beneficiation practices.

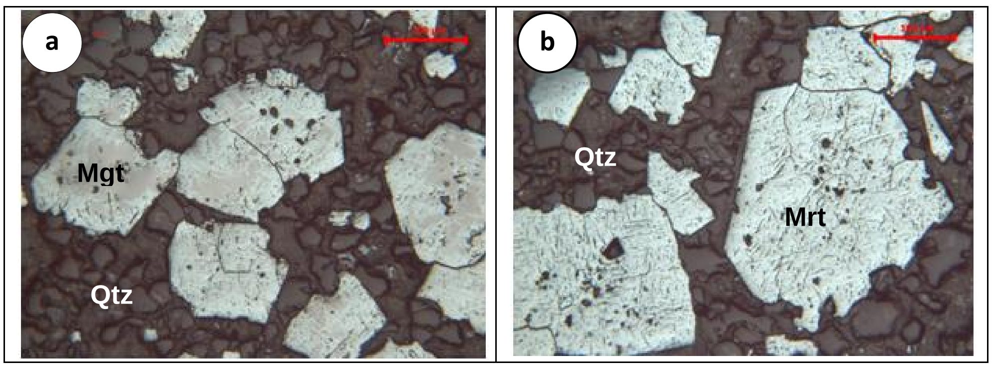

Fig 1. Photographs showing the characters of low-grade Goan ores under optical microscope. (a): An association of magnetite (Mgt) which is partially martitised and quartz (Qtz). (b): The original magnetite has been completely oxidized to martite (Mrt).

On the contrary, the Gua ore from Jharkhand is very complex. The bulk ROM sample consisted of both lumps and fines. The lumps vary widely in their character from hematitic to goethitic or limonitic. In many instances, the lumps were partially lateritised. The Fe(t), SiO_2, Al_2O_3, and LOI content of the ore are 54.59%, 6.23%, 5.53%, and 5.40% respectively. The alumina content of 5.53% is unacceptable and is found to be the main problem of the ore. Therefore, a detailed characterization was done to find out the modes of occurrence of alumina. X-ray diffraction studies on the powdered head sample revealed the presence of hematite and goethite as the major mineral phases (Fig 2). Petrographic studies indicated that majority of the lumps consist of a mixture of hematite and goethite where sometimes goethite content is more and very often limonitic in nature. In some lumps the ore shows a banded character where alternate hematite bands are intermingled with clayey impurities (Fig 3a). Some of the hematites are really Martites (Fig 3b). Due to lateritisation the ore has undergone several episodes of solution, precipitation, replacement and recrystallization and therefore, presents a complex texture and structure. In many instances hematite is overgrown by goethite (Fig 3c). Goethite is entrapped within clay or occasionally within gibbsite (Fig 3d). The gangue minerals identified are mostly clay (kaolinitic) and quartz (or amorphous silica). Independent quartz grains though recorded are very rare. However, clay is ubiquitous in fracture planes, grain boundaries and weathering pits. Gibbsite is found to occur in crystalline forms as independent grains as well as in replaced relics intimately associated with goethite. SEM studies confirmed the findings of optical microscope and one such finding i.e, the presence of clay in the inter-granular grain boundaries of iron bearing phases has been presented in Fig 4.

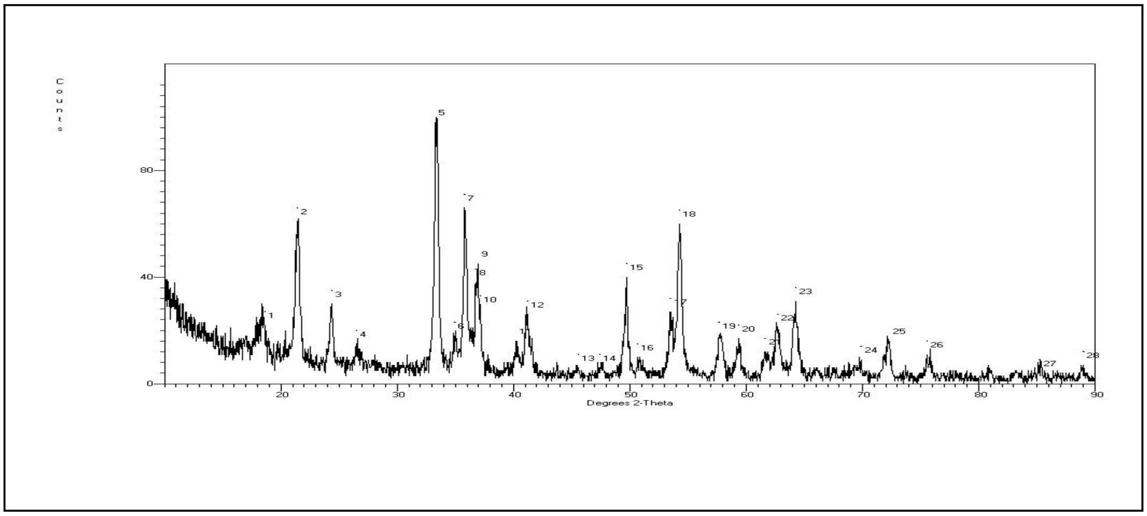

Fig. 2**:** X-ray diffraction pattern of the low-grade iron ore from Gua, Jharkhand showing peaks of dominating mineral phases: Hematite (5) and Goethite (2) at 2.70Å and 4.18 Å respectively. The secondary peaks matches well with the JCPDS data file.

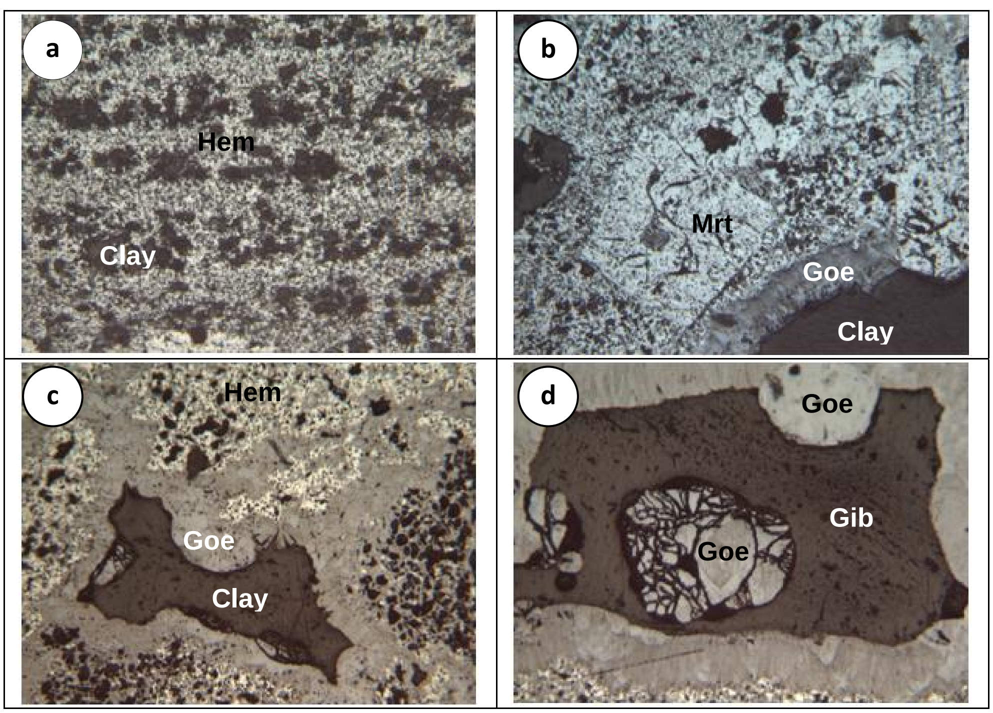

Fig. 3: Optical photographs showing bands of hematite (Hem) inter-banded with clay (a), martite (Mrt), goethite (Goe) and clay (b), growth of goethite (Goe) over hematite (Hem) (c), and inclusion of goethite (Goe) within a mass of gibbsite (Gib) (d).

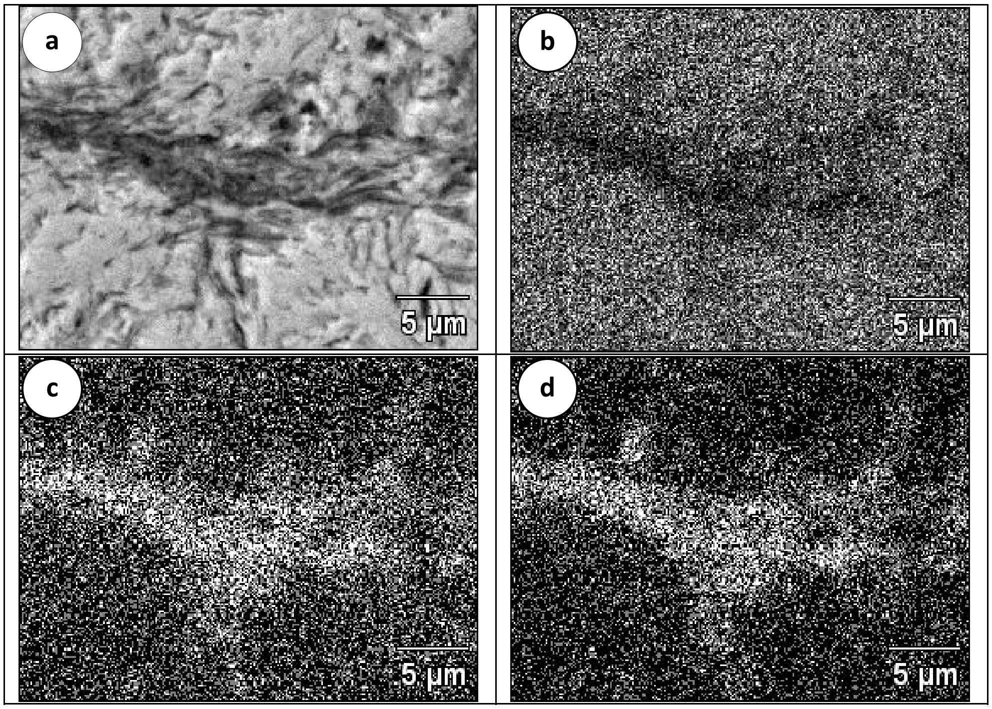

Fig. 4: SEM micrographs showing occurrence of clay (crystallites in the darker shade) in the inter-granular grain boundaries of iron mineral (a). Figures (b), (c) and (d) show elemental maps of Fe, Si and Al respectively in the area shown in (a).

These observations in case of the low-grade iron ore of Gua, Jharkhand clearly indicate that the liberation characteristics of this ore shall be very poor. The minerals are so intricately associated with each other that they shall not be easily detached. Moreover, the distribution of alumina in form of clay that occurs in extremely fine crystallites (<5μm) in grain boundaries and as adsorption in goethite are almost impossible to release by normal crushing operations.

4. Conclusions

The low-grade ores of Jarkhand contains ~ 54% Fe. Alumina (Al_2O_3) which is the main problem in this type of ore (or generally in Eastern India) is found to occur associated with clay, gibbsite and as adsorption in goethite. Textural evidences indicate that while it may be possible to remove these gangue phases when present in coarse and well crystalline form, it will be quite difficult to liberate the intra-granular impurities that are bound within hematite and goethite in micron levels. On the contrary, the tenor/grade of the Goan ore is much less (~43% Fe) compared to the ore of Jharkhand. However, the alumina problems do not occur in the studied Goan ores where the iron-bearing phases are not chemically contaminated and are liberated well by comminution. These mineralogical studies indicate that though the Goan ores are low in Fe content, these can be beneficiated to get a higher grade (+63% Fe) with a high recovery while it will be difficult to improve the Jharkhand ores to similar grade with higher yield. Therefore, it is not the Fe-content but the type of Fe-bearing mineral present in the ore which will dictate the yield and grade of the beneficiation products.

5. Acknowledgements

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6. References

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