GEOLOGICAL CHARACTERÍSTICS OF IRON ORES FROM QUADRILÁTERO FERRÍFERO

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ABSTRACT

Large deposits of high grade iron ores and banded iron formations (locally known as itabirite) in Quadrilatero Ferrífero, in Minas Gerais State, Brazil, have been extensively mined. The usual classification of quality of lump and fine ores in the iron and steel industry in Brazil has been usually based on chemical analysis and granulometric and physical parameters. Little consideration has been given to the geological, microstructural and mineralogical characteristics that also influence the performance of agglomeration and reduction processes. Different typological categories of Brazilian iron ores have been used in these industrial processes. In this paper aspects of geology, mineralogy, fabric and typological classification of iron ores from Quadrilátero Ferrífero are discussed with special reference to these metallurgical processes.

Keywords: Iron Ore, Geology, Mineralogy, Fabric, Quadrilátero Ferrífero

1) INTRODUCTION

The intrinsic quality of iron ores charged into blast furnace and used in agglomeration processes in Brazil has been mostly evaluated using the traditional concepts of extractive metallurgy, which does not give much importance to the characterization of the microstructure and mineralogy of these materials. The iron is normally analysed as a raw material composed of iron oxides, gangue and other constituents considering physical, chemical and granulometric characteristics as the main parameters in the control process, but microstructural and mineralogical features are given little emphasis.

Recent works have highlighted the importance of geometallurgical studies in order to improve these and others industrial processes. [1-4] . The Brazilian ores from different mines or from the same mine have different geological atributes due to the conditions of metamorphism, tectonism and weathering during geological time [3-5][6-9]. Iron ores are polycrystalline material that have undergone several complex natural processes during geological time such as cold and hot working, annealing, recrystallization and weathering. These result in different intrinsic characteristics (mineralogy, crystal size, morfology of crystal, pore size, porosity, fabric, texture, fluid inclusion, etc) that consequently influence the metallurgical and physical characteristics of the lump ores (such as strength, decrepitation, reducibility, granulometric desintegration during reduction at low temperatures, behaviour, softening and melting parameters, etc) and fine-grained iron ores (such as sinterability, fusibility, wettability, capacity of cold agglomeration, etc).

2) MINERALOGY AND FABRIC OF IRON ORES FROM QUADRILÁTERO FERRÍFERO

The most important deposit of iron ores in Brazil came from proterozoic banded iron formations in the Quadrilátero region (Fig. 1) [10]. This region comprises an area of approximatly 7000 km^2. The Quadrilátero Ferrífero consists in an Archaen-Proterozoic granite-grainstone terrain and is one of most studied area in Brazil, mainly due to its important mineral resourses.

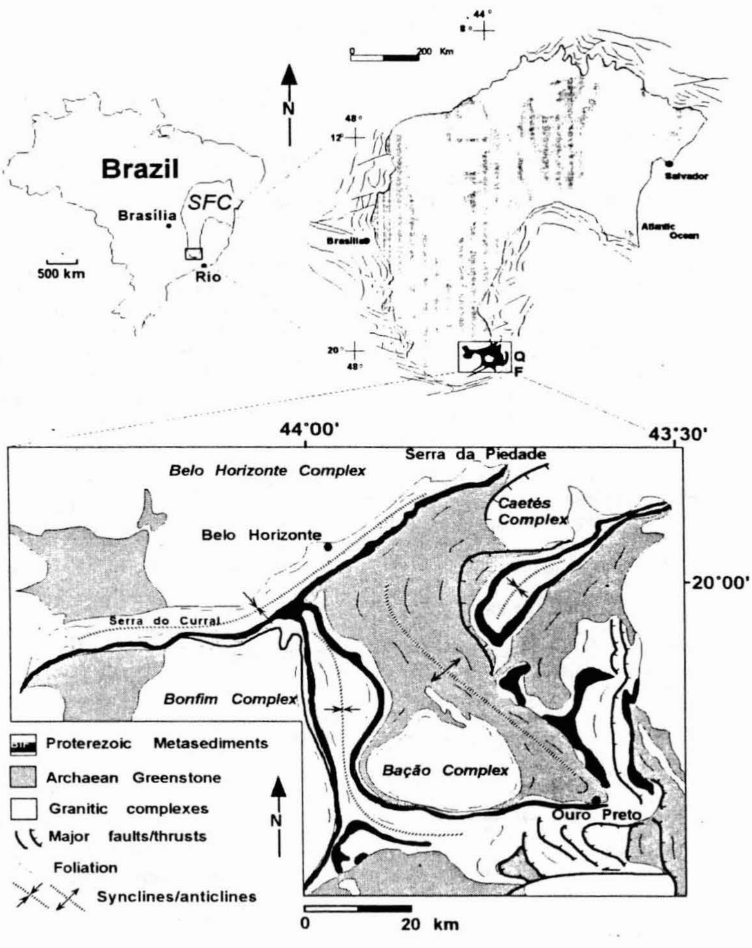

Figure 1. Simplified geological map of the Quadrilátero Ferrífero area (After Dorr, 1969).

In the itabirites and high grade ores of the Quadrilátero Ferrífero area, the mineralogy is determined by the following sequence of iron oxide generations [3-4]:

Magnetite I → Hematite II, III, IV
Hematite I, II → Magnetite II, III, IV
Magnetite II, III, IV. → Martite II, III, IV

Magnetite I is the oldest ore mineral found in the itabirites and rich ores in the Quadrilátero Ferrífero. It has a pink-brownish color under reflected light and corresponds to kenomagnetite which may be considered an non-stoichiometric variety of magnetite. In some cases, kenomagnetite oxidizes to maghemite. Kenomagnetite is usually progressively martitized along the crystallographic {111} planes and/or from the border inwards preferentially through microcracks and holes. Progressive martitization and subsequent recrystallization, through grain boundary migration processes, results in small in aggregates of hematite grains (hematite I), whose dimensions dimensions vary from 10μm to 200μm. These grains frequently display lobate to straight boundaries where magnetite relics can be still recognized resulting in a porous granoblastic microfabric.

This type of fabric can also be observed in iron ores from low metamorphic areas in Brazil such as those of Carajás and Urucum. A mixture of that microfabric with fine platy hematite grains results in type of ores which has a typical decussate microfabric.

The further progression of recrystallization under higher temperatures gives rise to the development of a granoblastic fabric of hematite crystals (hematite II) with straight boundaries and no kenomagnetite relics. The recrystallization of hematite and martite with increasing deformation allows the development of elongated platy crystals of hematite (here called specularite) where its basal plane defines a schistosity and its longest dimension characterizes a conspicuous mineral lineation resulting in lepidoblastic and nematoblastic fabrics. Specularite of this generation may be also regarded as hematite II that developed under tectonic conditions.

Associated with younger structures developed along the tectonic history of the Quadrilátero Ferrífero new sequential specularite generations may form by recrystallization at the cost of earlier crystals or by crystallization from remobilized fluids, giving rise to hematite III, IV and so on. According to their relative age they may vary depending on the position and tectonic history of the area. The influence of annealing and secondary recrystallization is variable depending on the temperature and pO_2 conditions resulting in the growth of granoblastic and idioblastic hematite (hematite IV) or magnetite (magnetite II, III), corresponding also to further generations of iron oxides. This can be more easily recognized on the eastern parts of the QF where predominates a higher metamorphic grade or near contact aureoles where new iron oxide blasts develop. Magnetite of these late generations proves also to be unstable since it appears mostly as partially oxidized kenomagnetite and was martitized to several degrees during the geological history (martite II, III, IV).

Grain orientation of hematite during recrystallization to specularite also results in a lattice preferred orientation and in a physical and magnetic anisotropy of the ores that can be measured by X-Ray or neutron diffráction and geophysical methods. As a first approach we can define three main types of iron ores based on the fabric characteristics as presented in Table 1. A quantitative parameter to characterization of the fabric and texture is also possible to determine the definition of a orientation tensor and the calculation of its eigenvalues and eigenvectors.

Besides the importance of the mineralogical and textural characteristics of the iron oxides, a quantitative determination of the accessorial mineralogy must be also accomplished in iron ore petrography, as the presence of manganese oxides (pyrolusite, psilomelane), silicates (amphiboles, pyrophyllite, chlorite, kaolinite) and secondary hydroxides (goethite, limonite) may interfere in the concentration and metallurgical processes.

Table 1 - Main types of fabrics of Brazilian iron ores

Types of fabrics and Mines	Description
Granoblastic Ex: Mutuca, C. do Feijão, etc. from Quadrilátero Ferrífero -MG; Carajás	Irregular intergrowth of xenoblastic hematite crystals and martite aggregates. Crystal borders are embayed to lobate.
Lepidoblastic Ex: Andrade, Caue, Morro Agudo, etc. from Quadrilátero Ferrífero -MG	Well developed platy hematite crystals (specularite) due to anisotropic growth parallel to the basal plane.
Mosaic Ex: Andrade, Morro Agudo	Isometric hematite crystals with straight, well-developed borders
Lepidogranoblastic	Specularite with granular hematite/martite in a mixed fabric

Ex: Casa de Pedra, Cauê, Andrade	
Microgranular Ex: Carajás, Corumbá	Micro - to cryptocrystalline hematite disposed in a very fine granoblastic fabric
Decussate Ex: Carajás	Fine platy interlaced crystals disposed in lattice-like distribution

3) AGGLOMERATION AND REDUCTION OF IRON ORES

Many types of characteristics are used to analyse the intrinsic quality of fine ores employed in the sintering and pelletizing processes, such as chemical composition, granulometric parameters, specific surface, porosity, cold agglomeration capacity, etc, as well as process variables and their influence on the quality of the agglomerated end product [12-17]. Studies[2][18-20] have shown that many types of iron ores used in the reduction process have characteristics related to their mineralogy, microstructure and fabric. From the point of view of these parameters martitic lump ores from Quadrilátero Ferrífero containning low magnetite content (or kenomagnetite) and low gange content were found to be satisfactory as charging material for mini-blast furnace [2] (very low RDI, low decrepitation index, very good softening and melting parameters and good reducibility). On the other hand, lump ores which has suffered a high deegre of metamorphism and tectonism did not lead to very efficient performance when compared to martitic lump ores [2].

Some studies in literature have discussed the importance and relationship between microstructural characteristics and the efficiency of cold and hot agglomeration stages of iron ores in the sintering process [21-25]. The size, shape and distribution of crystals and ore pores, among other factors, influence the reducibility of sinters [23]. Goethitic ores have a remarkable effect in the structure of melted part of the sinter, influencing the formation of calciumferrites, vitreous slag and porosity which in their turn control the metallurgical and mechanical parameters such as reducibility, strength, RDI, etc [26]. Limonitic ores have an influence on the melting temperature of adherent particles [27]. Appropriate choice in terms of grains size and proportion of hydrated ores in the sinter mix, along with compact hematites, contributes to enhance the reducibility of sinters [25]. The use of hydrated ores affects the relation between the liquid phase and the nuclei in the sintering process [24]. The intensity of granulometric degradation of sinters during reduction at low temperatures is strongly influenced by its microstructural constituents [17].

The importance of mineralogical parameters of iron ore fines used in pelletizing in the industrial process have also been discussed [28-30] in different contributions. The use and performance of different types of Brazilian ore fines like specularitic, martitic and hydrated in some stages of concentration, preparation and pelletizing processes have been discussed in other contributions [31-34].

Due the great variety of types of Brazilian fine iron ores for use in industrial processes, as well as the actual problems associated with the mining and market demand, the interest to include geometallurgical studies is gaining increasing importance [20] [35].

4) THE TYPOLOGICAL CLASSIFICATION OF BRAZILIAN IRON ORES

Different typological categories of Brazilian iron ores have been used in the industrial processes of reduction and agglomeration [2][19,20]. Several kinds of hematite crystals like specularite, martite and microgranular hematite, etc. with variable crystal sizes from 1μm to 1000 μm are found in the different ore types. As show in Table 1, the fabric may be granoblastic, lepidoblastic, granolepidoblastic etc. They are also composed of different types of accessory mineralogical constituents such as kaolinite, gibbsite, goethite and have different porosities and pore diameters, which influence the stages of agglomeration and reduction of the fine ores

The classification of iron ores based on genetic criteria cannot be used with success in mining and metallurgy to make a good characterization due to the variety of geologic phenomena involved in the formation of the ore deposits[35]. As a first approach to an industrial classification of Brazilian iron ores, it is suggested to use a very simple nomenclature based on its dominant mineralogy.

The first step would be in a taxonomic table based on two main types of division, namely magnetitic and hematitic.

The hematitic ores could belong to different categories. Martitic ore (Mutuca Mine), where most of hematite would derive from the oxidation of magnetite. Granular ore, constituted of granoblastic (Pico Mine), microgranular or cryptogranular hematite, (Carajás and Urucum Mines). Specularitic ore (Andrade and Caue Mines), constituted mainly by tabular or specular hematite.

Goethitic and limonitic ores would represent a third subordinate type, when hydroxides are present in proportions high enough to interfere in its use in the metallurgical process. As Brazilian iron ores are concerned, the goethitic term must be preferentially added to the others like goethitic martitic ore (Alegria Mine), goethitic specularitic ore, etc.

In Brazil, it is not common to find magnetitic ores to use in industrial processes. Most of the time this mineral appears as relics of kenomagnetite, so it would be more realistic to use for the classification of iron ores terms like kenomagnetitic martitic ore (Feijão Mine) or goethitic kenomagnetitic martitic ore (Alegria Mine), etc.

Additional information such as porosity, fabric, anisotropy and accessorial mineralogy (*kaolinitic, gibbsitic, etc*) or physical properties (compact, friable, schistose, etc.) could be added as characterization parameters.

5) CONCLUDING REMARKS

The variability of types of microstructure, mineralogy, texture and fabric of the Brazilian iron ores is a consequence of its geological evaluation, considering the difference of regional domainal, caused by the variable intensity of metamorphism, tectonism and weathering. As a consequence, different mines have different categories of iron ores with distinct metallurgical behavior. To control the industrial process, it is essential to evaluate the internal identity (mineralogical constituents, porosity, morphology and size of crystals and pores, fabric, texture, shape and types of particles surface, etc) of the lump ores, fine ores or mixtures of raw materials used in the agglomeration and reduction processes.

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