Important iron ore characteristics and their impacts on sinter quality – a review

L. Lu

Principal research scientist, CSIRO Mineral Resources Flagship, Kenmore, Queensland, Australia
Email: liming.lu@csiro.au

Abstract

In this review, the sintering process is first described and analyzed to identify the key factors affecting the structure and quality of iron ore sinter. Under fixed sintering conditions, the granulation efficiency, nucleus stability and primary sinter melt volume and properties of the iron ore are considered to have significant influence on the sinter structure and quality. Discussion is then focused on the effects of the chemical, physical and mineralogical characteristics of the iron ore on these key factors, and the consequences for sinter quality.

Introduction

Sintering is the most economic and widely used agglomeration process to prepare iron ore fines for blast-furnace use. In modern blast furnaces, particularly in East Asia, iron ore sinter typically constitutes more than 70% of blast-furnace ferrous feed. High sinter quality and efficient sinter production are thus required both to withstand extreme operating conditions and maintain the productivity of modern blast furnaces. At the same time, due to the increasing depletion of high-grade iron ore resources from large deposits, iron ore producers are moving toward developing an increasing number of deposits of much smaller sizes to maintain current production levels. It is therefore imperative for iron ore producers to develop long-term strategies to maintain the quality and consistency of the iron ore fines they are producing while exploiting these smaller, complex deposits. The iron grade, gangue minerals present, overall mineralogy as well as physical characteristics of iron ore fines being mined from these different deposits vary considerably. Overall, ores now have highly complex mineralogy, are becoming more porous and friable, and contain increasing amounts of gangue minerals, which will have important implications for the sintering process and sinter quality.

Blending is one of the most effective options being explored by iron ore producers to deal with multiple small complex deposits. This allows the iron ore producers to reduce the number of products and take full advantage of the unique characteristics of each individual deposit to achieve long-term product consistency while increasing production. Blending is also a common practice in sinter plants as it is almost impossible to produce from one single ore a high-performance sinter mixture with the required processing characteristics. A typical sinter mixture used in Japanese steel mills (Nakano and Okazaki, 2007; Matsumura et al., 2013) often contains five or more ores to achieve balanced sinter quality and productivity with relatively low cost of raw materials.

When designing an ore blend, the blend components are selected to support each other in achieving good overall metallurgical performance of the final ore blend at optimum raw material cost. To do so, a fundamental understanding of the key characteristics of iron ore fines and their potential impact on the sintering process and sinter quality are needed. However, previous studies in this domain have focused more on the processing variables (Loo and Wong, 2005a; Loo and Wong, 2005b; Lu and Holmes, 2008) and less on ore characteristics (Loo, 2005; Okazaki and Higuchi, 2005; Lu et al., 2008; Hsieh, 2005; Umadevi et al., 2011). These papers have focused on certain specific aspects of ore characteristics and their impact on sintering performance. In this review, the effects of the chemical, physical and mineralogical characteristics of the iron ore fines are systematically discussed, based on current understanding of the formation of sinter structure during sintering.

Iron ore sintering process

Process description. The counter-current principle on which a blast furnace operates makes it heavily reliant on the quality and size of its burden to maintain sufficient levels of gas

permeability in its upper shaft and liquid and gas permeability in its lower part. The sintering process converts iron ore fines of < 6.3 mm into larger agglomerates between 5 and 50 mm, which possess the physical and metallurgical characteristics as well as gas permeability required for efficient blast-furnace operation. The sintering process is carried out in two stages: granulating and firing of a carefully blended sinter mixture of fine iron ores, coke breeze and other additives, such as fluxes and recycled ferruginous materials from downstream iron and steelmaking processes.

Granulation is carried out in a granulation drum after mixing, by controlling the moisture content and the particle motion of the sinter mixture, sometimes with the help of binders, to achieve a much coarser size distribution compared with the original sinter mixture. The principal mechanism for the granulation process is the layering of fine particles (often -0.25 mm in size) onto coarser particles (often +2 mm in size) (Lister, 1990). The granulation process also facilitates the even distribution of fuel and fluxes that are required for the agglomerated product. The green granules are then loaded to a depth of 0.5-0.85 m on a sinter strand of continuous grate, moving continuously at typically 2-3 m/min. The sinter strand is normally about 4-6 m wide with an effective sintering area of up to 600 m^2.

Firing is initiated when the green granule bed passes through a series of gas burners, which ignite the coke particles at the surface of the bed. The heat generated from the combustion of the coke particles continues to raise the temperature of the layer to achieve partial fusion and generate a melt phase first from adhering fines and then by assimilation of coarse particles, which on cooling solidifies into a sinter matrix that bonds the initially loose iron ore particles into lumps of clinker-like material. The peak temperature of the burning coke layer (also called the flame front) reaches approximately 1300-1375°C. The downdraft suction applied to the sintering bed helps to preheat the air sucked in from the top as it passes through the flame front, to cool the sintered bed, and to heat and ignite the coke particles in the layer below the flame front. This allows the flame front to move downward until it reaches the bottom of the sintering bed (the burn-through point), just before the discharge point of the strand. At the end of the strand, the sintered product falls off the grate into a breaker and then onto a rotary cooler.

Key factors affecting sinter quality. Sinter quality is determined by the structure of sinter. Figure 1 shows the macro- and micro-scale structure of a typical pot-grate sinter particle. At a macroscopic level, iron ore sinter ideally consists of a porous matrix with an appropriate proportion of relict ore nuclei. It is clear that sinter matrix acts as a glue to bond the sinter structure together and therefore plays a key role in achieving sinter quality. Microscopically, the solidified sinter matrix generally consists of complex calcium ferrites known as SFCA (silico-ferrite of calcium and aluminum), glass and silicates (such as larnite: Ca_2SiO_4), as well as secondary magnetite and hematite grains (precipitated from sinter melt). Depending on the conditions under which the sinter matrix is formed, two major forms of SFCA with different morphologies are recognized under an optical microscope; prismatic SFCA (top right) and platy SFCA-I (bottom right). From recent in situ synchrotron X-ray diffraction studies, it was found that SFCA-I only forms during heating while SFCA forms through crystallisation of the primary sinter melt (Webster et al., 2012). Studies (Pownceby and Clout, 2002; Ishikawa et al., 1982) suggest that SFCA-I is a desirable sinter bonding phase, due to its interlocked structure and microporous nature, making sinter stronger and more reducible.

Since the sinter matrix is solidified from the primary sinter melt, the quality and quantity of the sinter matrix are dictated by the amount, composition and properties of this melt. Sintering is a nonequilibrium process, because the flame front is pulled down quickly under suction. Hence, only the fine and most reactive components of the sinter mixture fully partition to form the initial sinter melt, which evolves during the process through its interaction with the surrounding fine and coarse materials. Therefore, the amount, composition and properties of primary sinter melt depend not only on the fine, reactive components but also on the interaction between the melt and its surrounding coarse nucleus particles. Finally, as the sinter matrix is inherited from the green granule bed, the bed structure of green granules will therefore have a certain impact on the matrix formed, particularly the pore and void structure. Figure 2 summarizes the key factors affecting the structure and resultant quality of sinter. Under fixed sintering conditions, granulation efficiency, nucleus stability and properties and volume of sinter melt play important roles in determining sinter structure and
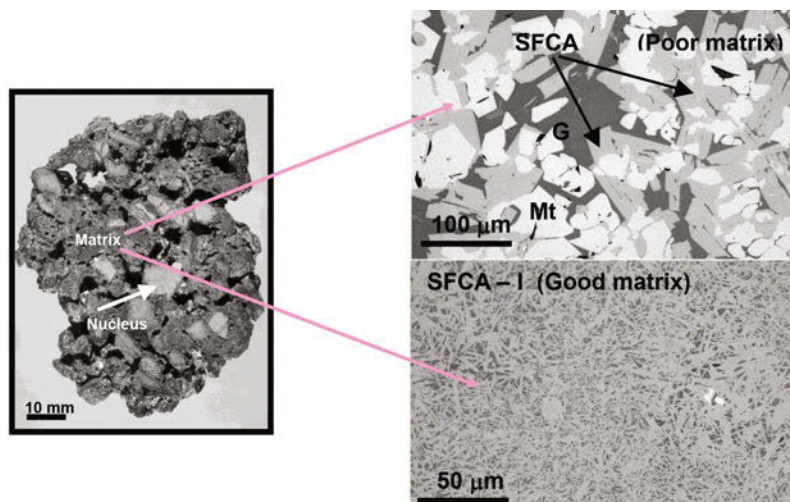

Figure 1 — Macroscopic and microscopic structure of a typical pot-grate sinter particle. SFCA: silico-ferrite of calcium and aluminum, Mt: magnetite and G: glass (Scarlett et al., 2004).
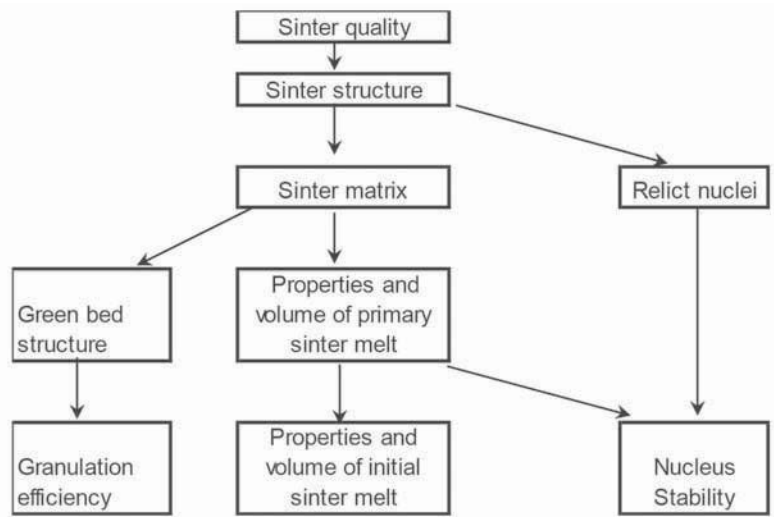
Figure 2 — Schematic showing the key factors affecting sinter structure and resultant sinter quality.

quality. Hence, it is important to understand how the principal ore characteristics affect these key parameters.

Effect of ore chemistry on sinter quality

Chemically, iron ore fines consist mainly of various iron oxides including hydrated oxides and oxyhydroxides and different amounts of gangue minerals. While the majority of the iron present in the iron ore fines is typically in the form of hematite (Fe_2O_3), some iron ore fines also contain a considerable amount of goethite [$FeO(OH)$], magnetite (Fe_3O_4) and other meta-stable forms of iron oxides. Key impurities in iron ore fines include silica (SiO_2), alumina (Al_2O_3), sulfur (S), phosphorus (P), magnesium oxide (MgO), calcium oxide (CaO) and a varying amount of loss on ignition (LOI) components. The LOI components predominantly include hydrated iron oxides and to a lesser extent carbonates and other volatile minerals. Since the LOI components are closely related to the ore mineralogy, its impact will be discussed in a later section on ore mineralogy. Iron ore fines from certain regions may also contain small amounts of minerals containing titanium

(Ti), vanadium (V), copper (Cu), arsenic (As), chlorine (Cl) and alkali and alkaline earth elements. Titanium was found to have a deleterious effect on sinter quality (Bristow and Loo, 1992) while chlorine can cause serious environmental problems (Ooi and Lu, 2011). However, this discussion will focus on the key impurities, in particular, SiO_2 and Al_2O_3.

Extensive work (Clout and Manuel, 2003; Dawson et al., 1983; Dawson et al., 1985; Pownceby and Clout, 2002; Pownceby and Clout, 2003) has been carried out to understand the effect of the key gangue minerals on sinter structure, particularly the sinter bonding phase. Al_2O_3 was found to be essential for the formation of SFCA, but it also influences the amount and type of SFCA formed (Lu et al., 2007). Figure 3 shows the phase relationships of the Fe_2O_3-Al_2O_3-CaO-SiO_2 (FACS) quaternary system in the region relevant to iron ore sintering (Pownceby and Clout, 2002; Pownceby and Clout, 2003; Patrick and Pownceby, 2002). As shown in Fig. 3(b), two separate stability regions have been identified by the authors for SFCA and SFCA-I, with SFCA-I favored by high-Fe and low-Al_2O_3 composition. The morphology of SFCA was also influenced by the SiO_2 content, with prismatic SFCA having
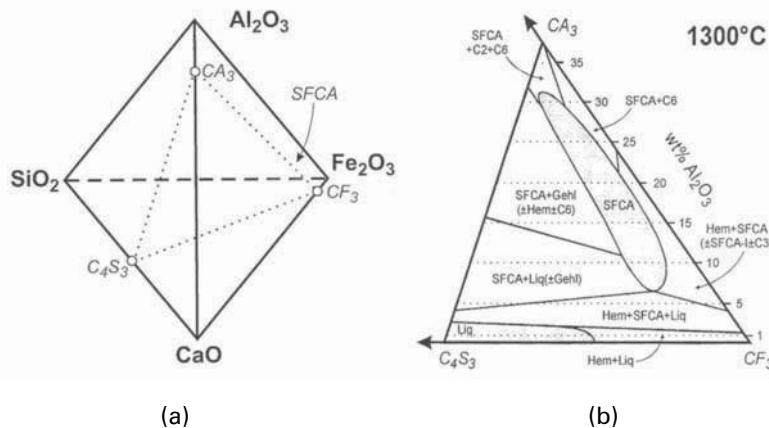

(a)   (b)

Figure 3 — Schematics showing: (a) the compositional plane (CF_3-C_4S_3-CA_3) for SFCA within FACS, and (b) the relationships of SFCA with surrounding phases at 1300°C within the CF_3-C_4S_3-CA_3 plane (Pownceby and Clout, 2002; Pownceby and Clout, 2003; Patrick and Pownceby, 2002).
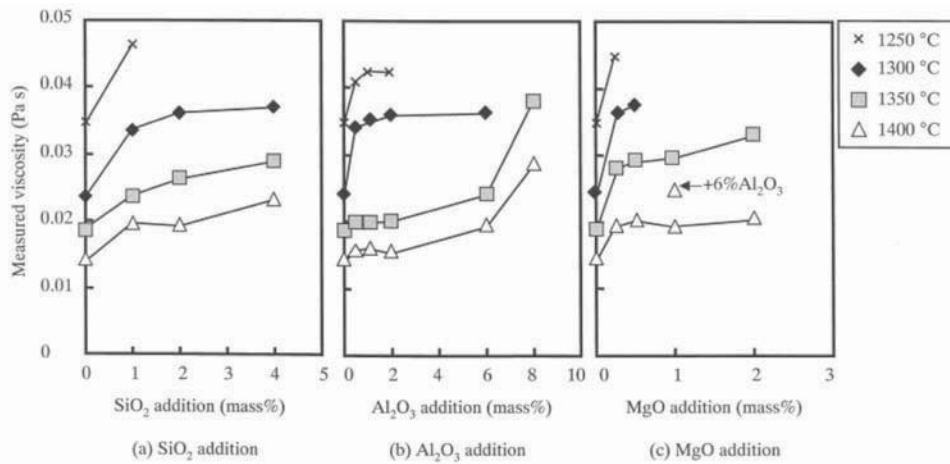
Figure 4 — Effects of SiO$_2$, Al$_2$O$_3$ and MgO on the viscosity of a simulated initial sinter melt generated from an 80% Fe$_2$O$_3$-20% CaO system (Machida et al., 2005).

(a) Alumina = 1.6 mass%   Alumina = 2.0 mass%   Alumina = 2.4 mass%

(b) Silica = 4.5 mass%   Silica = 5.5 mass%   Silica = 6.5 mass%

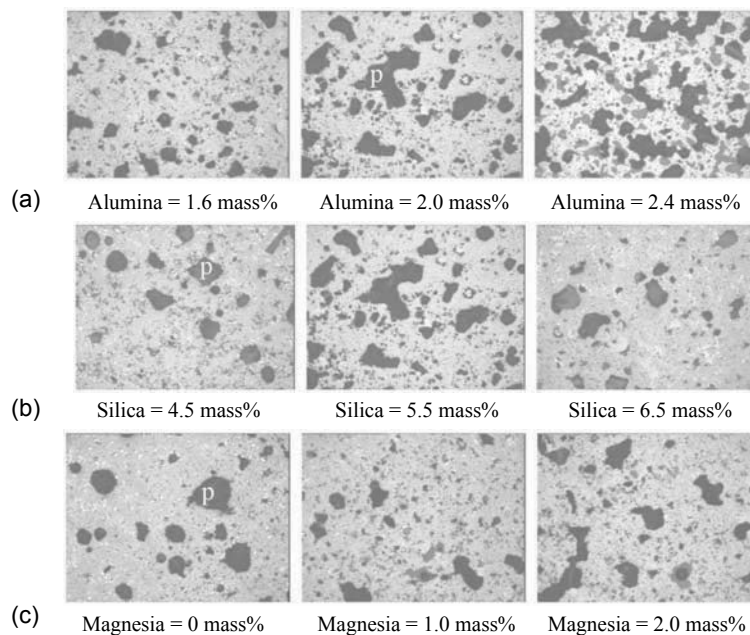(c) Magnesia = 0 mass%   Magnesia = 1.0 mass%   Magnesia = 2.0 mass%

Figure 5 — Optical micrographs showing the effects of SiO$_2$, Al$_2$O$_3$ and MgO on the pore structure of laboratory sinter (Loo and Leung, 2003). The dark areas labeled as "P" in the images are pores.

a lower SiO$_2$ content and fibrous SFCA having a higher SiO$_2$ content (Dawson et al., 1985).

Depending on their distribution, certain gangue minerals in the coarse nucleus particles can affect nucleus stability, which will influence the formation and properties of primary sinter melt, as discussed earlier. For example, our past experience has shown that ore particles from a higher alumina ore containing about 2.8% Al$_2$O$_3$ are not as reactive as ore particles of similar mineralogy but from a lower alumina ore containing about 1.5% Al$_2$O$_3$. Gangue minerals in fine fractions and reactive coarse particles, such as SiO$_2$, Al$_2$O$_3$ and MgO, readily enter the initial sinter melt formed mainly from fine Fe$_2$O$_3$ and CaO particles. This inevitably changes the composition and properties of the primary sinter melt and has important implications for the sinter structure and quality. Figure 4 shows the effects of SiO$_2$, Al$_2$O$_3$ and MgO on the viscosity of a simulated initial sinter melt formed from a low melting composition of the Fe$_2$O$_3$-CaO binary system (Machida et al., 2005). It is clear

that, at a constant temperature, the viscosity of the simulated melt increases with the addition of SiO$_2$, Al$_2$O$_3$ and MgO. At the sintering temperature (~1300°C), Al$_2$O$_3$ and MgO have more profound effects on viscosity than SiO$_2$. The rapid increase in viscosity in Fig. 4 is most likely related to the precipitation of solid phases. Figure 5 presents optical micrographs showing the effects of SiO$_2$, Al$_2$O$_3$ and MgO on the pore structure of laboratory sinter (Loo and Leung, 2003). Due to their impact on ore reactivity and melt viscosity, the gangue minerals can affect the consolidation of sinter melt and gas bubbles and hence the pore structure of sinter. This should have a drastic impact on sinter strength, size and yield. As shown in Fig. 5(b), the pore area was the highest at a silica content of 5.5 mass%. When the silica content was increased or decreased from the base level of 5.5 mass%, there was a greater degree of melt reshaping, resulting in more rounded pores. Figure 5(a) shows the effect of alumina on the pore structure of laboratory sinter. As the Al$_2$O$_3$ content increases, the pore area increases
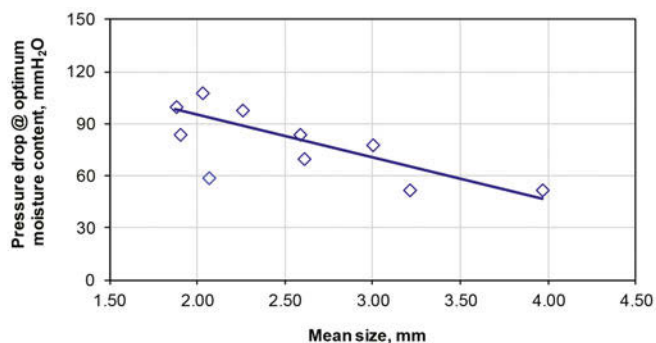
Figure 6 — Effect of mean particle size of iron ore fines on the pressure drop measured across packed beds of green granules prepared at the optimum mix moisture contents.

and the pore shape changes from well rounded to irregular, and finally to interconnected. It is apparent that as the Al_2O_3 content increased, the melt fluidity decreased, which reduced the ability of the bubbles in the melt to coalesce and reshape. In Fig. 5(c), compared with the sinter containing 2.0 mass% MgO, the sinter with no MgO shows relatively rounded, large discrete pores and a small amount of fine pores. There was reduced reshaping of pores at increasing MgO levels, probably due to changes in the melt liquidus temperature and viscosity as a result of the increasing MgO content.

In summary, ore chemistry, such as SiO_2, Al_2O_3 and MgO contents, affects not only the properties and formation of primary sinter melt but also the nucleus stability, which has important implications for sinter structure and quality. It is common for sinter plants to have fixed sinter chemistry targets in order to meet the subsequent chemistry targets required for their associated blast furnaces, in particular SiO_2, $CaO:SiO_2$ ratio (basicity),

and MgO. To achieve the same sinter chemistry targets, iron ore blends with lower SiO_2 and MgO contents require increased flux addition. Furthermore, as fluxing agents have a propensity to more readily enter the sinter melt phase, the melt formed from an iron ore blend with a lower SiO_2 content may form a sinter melt with a higher SiO_2 content than an ore blend with a higher natural SiO_2 level, even at the same sinter chemistry targets, leading to quite different properties of the sinter melt.

Effect of ore physical characteristics on sinter quality

Iron ore fines are characterized on a physical basis by variations in particle size, shape, surface characteristics and porosity. During granulation, the coarse +2 mm fraction of the iron ore fines provides the highest proportion of nonreactive nucleus particles, whereas the -0.25 mm particles largely partition to the adhering fines layers of the green granules. Some of the coarser intermediate particles (-2+1 mm) typically remain ungranulated. The particle size distribution of the iron ore fines is therefore one of the key physical parameters in determining the structure of the green granule bed, as it dictates the granulation efficiency and the final size distribution of green granules. As shown in Fig. 6, the pressure drop measured across the green granule bed prepared from different iron ore fines at their optimum mix moisture contents, and therefore the bed permeability of the green granules, improves as the mean particle size of the iron ore fines increases. In other words, the granulation efficiency improves with increasing mean size of iron ore fines.

Figure 7 shows the mean size and morphology of green granules formed from the same iron ore fines but with different loadings of ultrafine particles (-0.15 mm). It is clear that while increasing the fine particle loading does improve the granule morphology, it shifts the granule size distribution finer and reduces the mean granule size. Overall, increasing
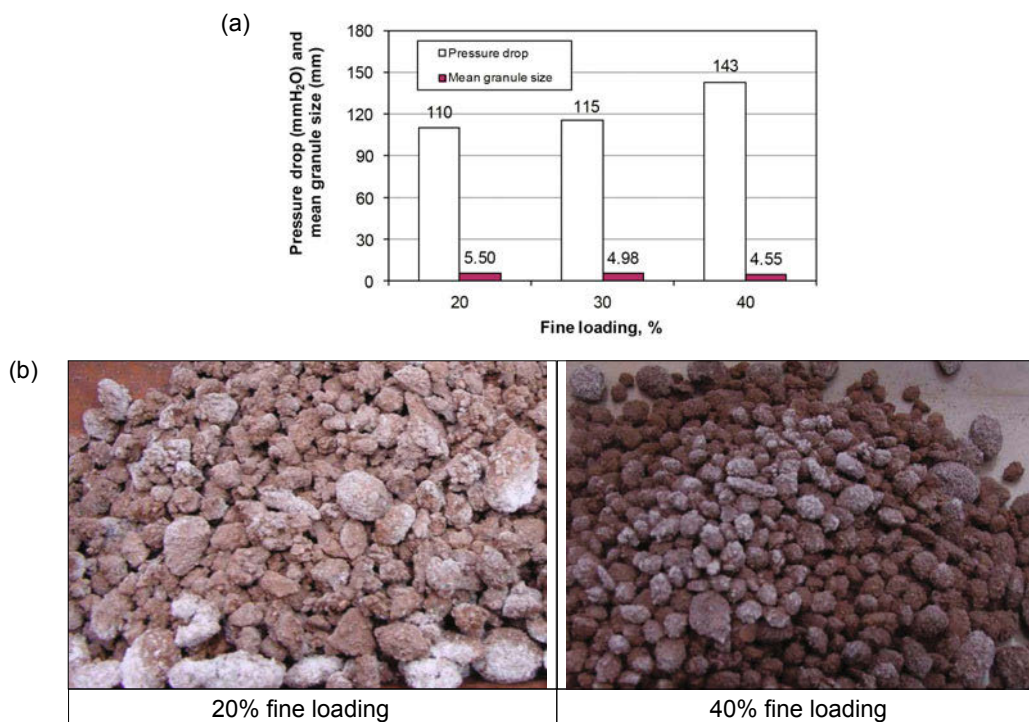
(a)

(b)

| 20% fine loading | 40% fine loading |

Figure 7 — (a) Pressure drop and mean sizes and (b) morphology of green granules formed from iron ore fines with different loadings of ultrafines.

the loading of ultrafine particles from 30 to 40% resulted in severe deterioration in the structure and permeability of the green granule bed. This is in agreement with findings reported in the literature (Lister and Waters, 1988; Nagano et al., 1985) that granulation efficiency decreases with increasing amount of fines.

The size distribution of iron ore fines affects not only the granulation efficiency, but also the formation of sinter melt. The proportion and stability of coarse particles influences the number of relict ore nuclei in the sinter structure. Relatively stable coarse particles are unreacted or only partially assimilated and act as "spacers" in the sintering bed, helping to improve the bed permeability at the flame front. Reactive particles are fully assimilated and contribute to the sinter melt. As finer particles have a higher surface area and contact more closely with fine flux particles, they react more readily with the flux to form an initial sinter melt at a lower temperature. The proportion of fine particles and nucleus stability therefore determines the volume and properties of the primary sinter melt formed during the sintering process. Figure 8 shows the strength and pore structure of laboratory sinters fired from the -1 mm fraction of the same iron ore fines containing different loadings of ultrafine particle particles (-0.15 mm). The detailed experimental method used was described by Clout and Manuel (2003). While both sinters achieved similar strength at higher temperatures, the sinter from the mixture with a higher loading of ultrafine particles developed the strength at slightly lower temperatures. From the pore structure shown in Figs. 8(b) and 8(c), both laboratory sinters have clearly started consolidation at 1265°C. However, compared with the sinter with 40% ultrafine loading, the sinter with 30% ultrafine loading appears to be slightly less consolidated at the same temperature, with considerably more small angular pores interconnected by thinner necks.

In addition, the physical structure of coarse ore particles, particularly particle shape, surface morphology and porosity, also affects the extent of fines adhering to them. It is understandable that smooth, platy and sharp surfaces will be less likely to accumulate adhering fines to form a continuous coating, while a well-rounded morphology and/or microporous surface texture will generally favor the formation of a well-developed coating. Similar considerations also apply to the morphology of the -0.25 mm particles. The effect of particle shape, sizing and porosity on granulation is clearly demonstrated in Fig. 9. Ores B and C had equigranular morphology and were relatively coarse with low amounts of ultrafines and intermediate particles, therefore both ores granulated effectively with well-developed coatings. The platy, angular morphology of Ore A did not favor the embedding of adhering fines onto the surfaces of its particles, however, resulting in less distinct adhering coatings. While Ores A and C had similar size distributions, Ore C also contains abundant goethitic
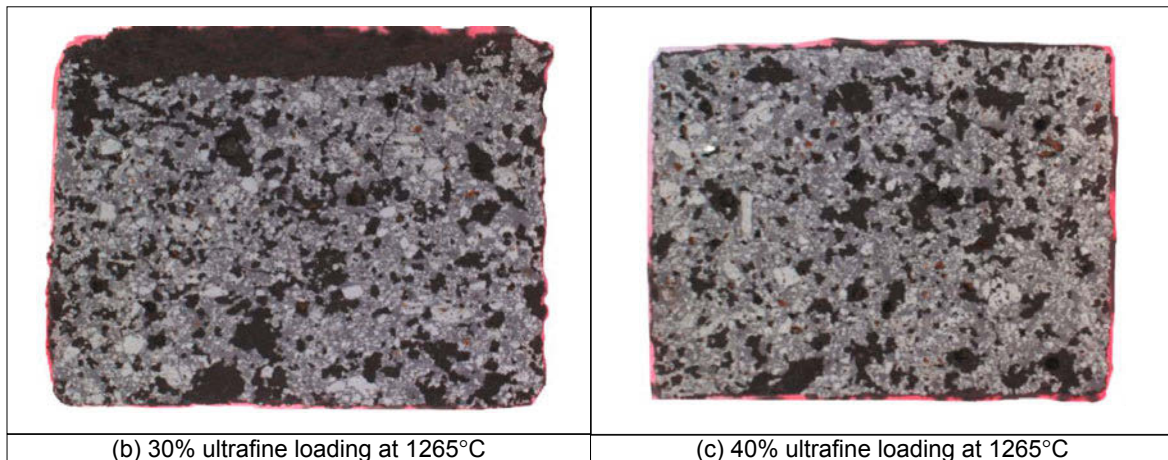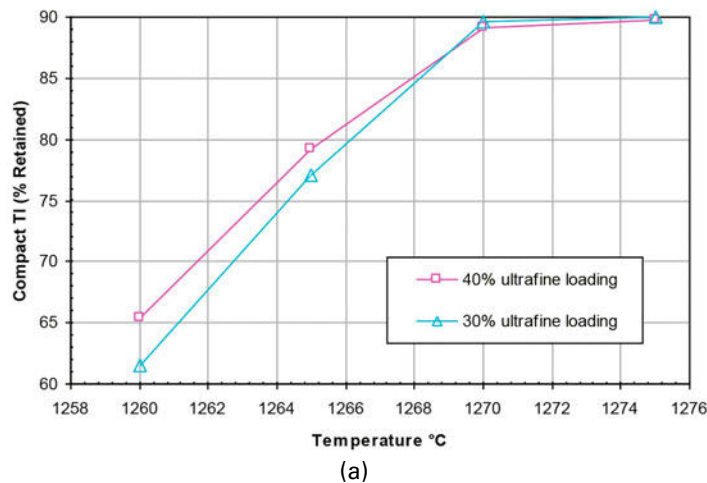

(a)

| (b) 30% ultrafine loading at 1265°C | (c) 40% ultrafine loading at 1265°C |

Figure 8 — (a) Compact Tumble Index (TI) strength (Clout and Manuel, 2003); (b) and (c) Pore structures of laboratory sinters fired from the -1 mm fraction of the same iron ore fines containing different loadings of ultrafine particles.

Figure 9 — Effect of particle shape and surface morphology on the morphology and structure of the green granules.

ultrafines, which adhere effectively to the surfaces of large particles and bind other fine particles together.

Ideally, an ore or an ore blend should avoid too much material in the intermediate size range and contain appropriate proportions of coarse and fine particles. Adhering fines will not only help contribute to the granule coatings, but will also contribute to matrix formation as well. From industrial practice, ores with relatively high proportions of coarse and fine particles and a relatively low proportion of intermediate particles are expected to granulate better. However, the boundary limits between the three size groups vary with individual ores. Other ore charac-

Figure 10 — Effect of primary porosity as measured by the moisture saturation of iron ore fines on the moisture content required to achieve efficient granulation.

teristics, such as porosity, shape and surface characteristics, can also affect granulation performance.

Effect of ore mineralogical characteristics on sinter quality

Mineralogically, iron ore fines are characterized by the occurrence and abundance of different iron and gangue minerals and their associations and texture. The importance of ore mineralogy was demonstrated by recent modeling work, which concluded that the inclusion of ore textural information can significantly improve modeling prediction of sinter quality (Donskoi et al., 2007; Donskoi et al., 2009).

Ore mineralogy and textural relationships determine the type of primary porosity present in iron ore fines, which influences the ability of iron ore fines to absorb and hold moisture during granulation. Since intraparticle pores need to be filled before surface water becomes available for interparticle adhesion, it is expected that iron ore fines with higher porosity need more water to achieve efficient granulation. Moisture saturation measures the ability of an iron ore fines sample to absorb and hold moisture before dripping out. Therefore, this value is expected to provide an approximate indication of the amount of water required for efficient granulation, as clearly evidenced in Fig. 10. As mentioned earlier, efficient granulation is a prerequisite to achieving good structure and permeability for the green granule bed. However, increasing mix moisture content will also affect the flame front temperature, width and speed due to the endothermic reaction for water evaporation. As for increasing limestone contents, increasing water load will lower the flame front temperature at the same coke addition (Loo and Wong, 2005b), which can adversely affect melt formation and sinter quality.
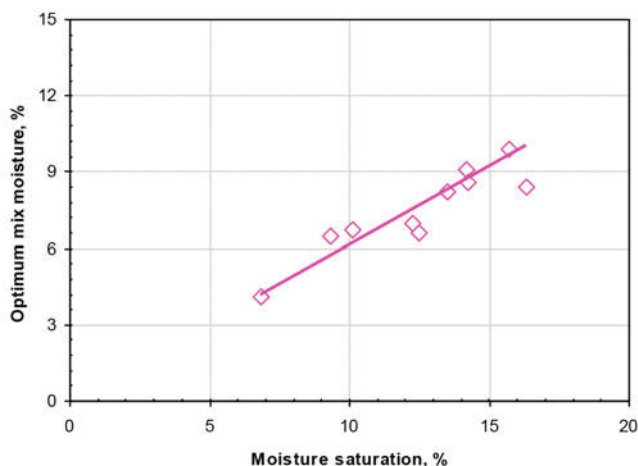
Ore mineralogy and textural relationships also determine the type and relative abundance of iron oxyhydroxides (for example, dense, vitreous goethite versus microporous, ochreous goethite) in an ore, which further determine the LOI components and ore bulk density. The LOI components of iron ore fines are released as temperature increases, leaving behind many secondary pores and cracks. The primary and secondary porosity will strongly affect the stability of nucleus particles in contact with the gas and liquid phases. Therefore, the mineralogy and texture of ore particles also play important roles in melt formation and retention of nuclei. Figure 11 depicts the differences in stability of typical hematitic and goethitic nucleus particles in a typical Japanese Steel Mill (JSM) sinter matrix. Ore A is composed largely of fine to very fine-grained microplaty hematite, which forms a moderately to highly microporous network. The microplaty hematite texture in Ore A is physically denser and harder than would be otherwise expected from its microporous microstructure. This explains the low nucleus assimilation rate and high retention rate of nucleus particles from this ore [Fig. 11(a)]. Ore C shows uniform texture and mineralogy typical of Channel Iron Deposit (CID) iron ores. The ore consists of concentrically zoned pisoliths of dense vitreous goethite, hydrohematite (whole pisoliths, pisolith layers or cores) and ochreous goethite, cemented together by porous vitreous-ochreous goethite. While this ore appears denser with some macropores but low microporosity, it consists predominantly of goethite, which generates large amounts of secondary porosity upon heating. Therefore, at the same firing temperature, the nucleus particles from Ore C are highly reactive and fully assimilated [Fig. 11(c)]. Ore B shows the typical characteristics of a Marra Mamba ore and contains both stable nucleus particles (dense and harder ore textures dominated by martite-goethite associations) and reactive nucleus particles from vitreous and ochreous types of goethite [Fig. 11(b)]. Release of LOI components also increases the gas volume generated within the sinter matrix creating the secondary porosity, which can result in a frothy texture, particularly where the melt viscosity is high and secondary pores are not able to consolidate. This can have a negative impact on sinter strength.

In addition, ore mineralogy and primary textural characteristics also affect the shape and size distribution of iron ore particles, both of which have important implications for the granulation characteristics, as discussed above. Ore size distribution will also play an important role in the formation of sinter melt and sinter structure. In the same crushing circuit, more friable ore textures tend to generate more fine materials. Ore particles of different mineralogical characteristics also tend to have different physical characteristics and are subject to different breakage mechanisms when crushed. As a result, some ore particles, such as Ore A in Fig. 9, are found to be platy with angular edges (usually hard, uniform ore types, which tend to undergo brittle fracturing), while others, such as Ores B and C in Fig. 9, are often equigranular or well rounded (including microporous textures, which tend to undergo size reduction by abrasion).

Ideally, a sinter structure requires about 30% relict nuclei to avoid excess melting and consolidation, and ensure sinter quality. Therefore, it is important when designing a sinter mixture to have an appropriate balance of mineralogy to maintain a sufficient amount of relict particles in the sinter structure but still generate sufficient sinter melt.

Conclusions

Under fixed sintering conditions, the granulation efficiency, nucleus stability and primary sinter melt volume and properties of the iron ore have important bearings on sinter quality. The effects of the chemical, physical and mineralogical characteristics of the iron ore on these key factors and therefore on the quality of the resulting sinter were discussed.

Iron ore fines consist mainly of various iron oxides including hydrated oxides and oxyhydroxides, different amounts of gangue minerals, and a varying amount of LOI components. Depending on their distribution within the ore and/or green bed, certain gangue phases such as Al_2O_3 and SiO_2 in the coarse nucleus particles affect nucleus stability, although they may remain segregated from the matrix. The same phases in the ultrafines fraction readily enter the initial sinter melt, formed mainly from fine Fe_2O_3 and CaO particles, and affect the properties of the primary sinter melt and the final sinter structure formed.

Physically, iron ore fines are characterized by wide variations in size, particle shape, particle surface characteristics and porosity. Particle shape, size distribution and porosity play important roles in determining the granulating characteristics of iron ore fines. The porosity of iron ore fines also affects the stability of nucleus particles and the reactivity of ultrafine particles which, together with the size distribution of the iron ore fines, determine the volume of the sinter melt as well as the amount of relict nuclei. The size distribution of iron ore fines also influences the partitioning of potential nucleus particles and matrix forming material and therefore plays an important role in the formation of the primary sinter melt.

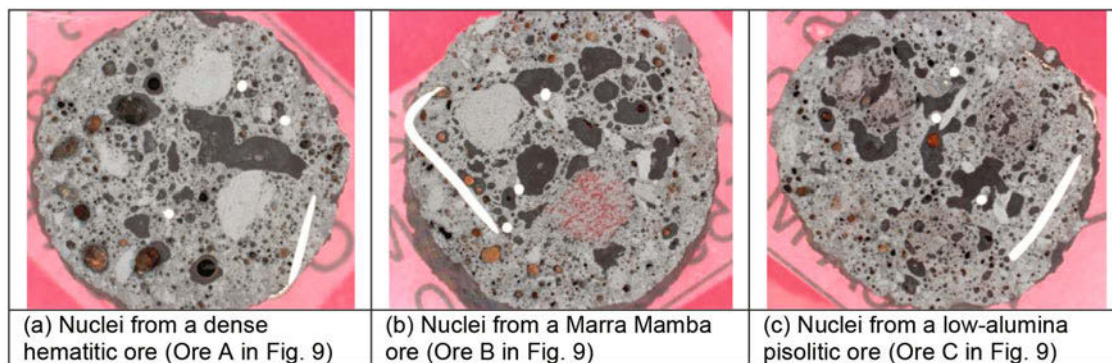Ore mineralogy determines the primary porosity present in

(a) Nuclei from a dense hematitic ore (Ore A in Fig. 9)

(b) Nuclei from a Marra Mamba ore (Ore B in Fig. 9)

(c) Nuclei from a low-alumina pisolitic ore (Ore C in Fig. 9)

Figure 11 — Stability of different types of nucleus particles at 1300°C in the matrix of a typical Japanese Steel Mill (JSM) sinter blend. Relict ore particles are presented as dense grey particles in (a) and (b).

iron ore fines, which directly influences the amount of water required for efficient granulation. Ore mineralogy as related to the characteristics of the deposit also determines the abundance of ore textures present, with the proportion of hydrated oxides and oxyhydroxides directly related to the LOI components. Therefore, there is a close link between ore mineralogy and the LOI components. Release of the LOI components from iron ore fines generates secondary porosity, which, together with primary ore porosity, influences the stability of nucleus particles and distribution of retained porosity in the sinter matrix. As the release of LOI components is endothermic, iron ore fines of higher LOI contents often require more fuel to maintain the flame temperature and sinter quality compared with those containing lower LOI contents. For a given crushing flowsheet, ore mineralogy also affects the shape and size distribution of iron ore fines, both of which have important implications for the granulating and sintering characteristics of iron ore fines.

Acknowledgments

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