TECHNOLOGICAL CHARACTERIZATION STUDIES ON IRON MINERALIZED SAMPLES[1]

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Abstract

This paper presents the technological characterization results of two iron ore samples. The aim of this study was define the iron oxi-hydroxides occurrence and their associations to the gangue minerals for establishment of the appropriate grinding conditions for further mineral processing, considering products with SiO_2 grades below 5%. For Ore 1 (higher Fe content), lump ore and coarse sinter feed can be obtained just by particle size analysis; however, fine sinter feed and pellet feed can be obtained, at the same comminution, after mineral separations to achieve the required specification. For Ore 2, the liberation of iron oxi-hydroxides occurs below 0.15 mm, so only pellet feed would be attained.

Key words: Iron ore; Technological characterization.

ESTUDOS DE CARACTERIZAÇÃO TECNOLÓGICA EM AMOSTRAS MINERALIZADAS A FERRO

Resumo

Este trabalho apresenta os resultados da caracterização tecnológica de duas amostras mineralizadas a ferro. O objetivo deste estudo foi avaliar a forma de ocorrência dos oxi-hidróxidos de ferro e suas associações com a ganga contida, de modo a estabelecer a granulação de moagem adequada para sua posterior concentração, considerando produtos com teores de SiO_2 inferiores a 5%. Para o Minério 1 (mais rico), verificou-se que há possibilidade de geração dos produtos granulado e sinter feed grosso simplesmente através de classificação granulométrica; já os produtos sinter feed fino e pellet feed podem ser obtidos, a partir da mesma cominuição, após separações minerais para atingir a especificação requerida. Para o Minério 2, a liberação dos oxi-hidróxidos de ferro ocorre somente abaixo de 0.15 mm, sendo possível apenas a obtenção do produto pellet feed.

Palavras-chave: minério de ferro; caracterização tecnológica.

1 *Technical contribution to the 2nd International Symposium on Iron Ore, September 22 – 26, 2008, São Luís City – Maranhão State – Brazil*
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1 INTRODUCTION

The present technological characterization study was carried out to appraise the nature of iron oxi-hydroxides occurrence and their associations with the gangue minerals, focusing on silicon, aluminum and phosphorus bearing minerals. The potential products and top size milling were defined based on the mineralogical associations and mineral separation, considering the final products specification (SiO_2 < 5%).

The studied samples, identified as Ore 1 and Ore 2, correspond to coarse iron ore samples from Colombia; these ores are locally processed.

Through this study, it was demonstrated that the technological behavior of the samples are very different despite the similarity on chemical and mineralogical compositions. The experimental comprehended comminution, sieving and mineral separation assays, followed by mineralogical studies through scanning electron microscopy and X-ray diffraction.

2 MATERIAL AND METHODS

The laboratory procedure involved basically two distinct routes. The first one aimed to obtain the different particle size products from the coarse fractions by comminuting the samples bellow 38 mm (top size for lump ore). The second comprised the detailed study of the potential products to be attained from the grinded ore, in a way to achieve SiO_2 grades below 5%.

Therefore, the adopted method for each sample was based on its own mineralogical and textural characteristics.[1, 2]

The following steps were defined according to the results obtained in the first activity.

The procedure adopted for Ore 1 comprised:

- crushing below 38 mm (1 ½”, top size for lump ore) in jaw crusher and sampling of representative aliquots by elongated piles;
- scrubbing of the crushed material in a concrete mixer (about 3 minutes) in a 50% solid-water slurry;
- wet size screening in the following apertures (mm): 25.4, 12.7, 6.35, 3.36, 1.19, 0.42, 0.15, 0.10, 0.074, 0.044 and 0.037;
- mineral separation by heavy liquid (tetrabromoethane, 2.95 g/cm^3) in fractions between 6.35 and 0.15 mm;
- disliming in hydrocyclone (estimated cut at 0,010 mm) of the fraction -0.037 mm, obtaining the -0.037 mm underflow (UF) and slime (overflow; OF);
- magnetic separation of the underflow product in wet high intensity magnetic separator (WHIMS).

For Ore 2, the following procedure was applied:

- crushing below 38 mm (1 ½”, top size for lump ore) in jaw crusher and sampling of representative aliquots by elongated piles;
- evaluation to obtain the different particle size products from the comminution at -38 mm (same procedure previously described);
- evaluation to obtain from the coarse sinter feed, through comminution of a new aliquot at -3.36 mm (roll mill, where a liberated quartz portion is evident), disliming of grinded material in hydrocyclone (splitting in around 0,010 mm), wet size screening of the dislimed material in 1.19 mm, 0.42 mm, 0.15 mm and 0.037 mm. Each fraction size was submitted to a magnetic separation by a RE roll magnetic separator for the fractions above 0.42 mm and by Frantz magnetic separator

(barrier model) for the fractions between 0.42 and 0.037 mm; WHIMS was performed for -0.037 mm underflow (UF).

- evaluation of atained equivalent pellet feed product, considering grinding below 0.15 mm of a new aliquot (estimated liberation size according to the previous step results) followed by disliming in hydrocyclone and wet size screening of the underflow in 0.074 and 0.037 mm. Heavy liquid separation (tetrabromoethane, 2.95 g/cm^3) were carried for the fractions above 0.037 mm and also -0.037 mm underflow as well as magnetic separations for the fractions between 0.15 and 0.037 mm by Frantz magnetic separator (barrier model) and in WHIMS for -0.037 mm underflow (UF).

3 RESULTS

3.1 Chemical Composition

The chemical composition of the studied samples is shown in Table 1.

Table 1. Chemical composition of the studied samples (assayed grades)

Grades % (w/w)	Ore 1	Ore 2
Fe	59.4	51.9
SiO_2	2.86	10.6
Al_2O_3	0.88	3.82
P	0.09	0.06
Mn	2.84	0.76
TiO_2	0.04	0.19
CaO	0.05	1.11
MgO	0.04	0.37
Na_2O	0.05	0.13
K_2O	0.12	0.72
LOI	10.3	8.26

3.2 Ore 1

The summary of particle size analysis for comminution at -38 mm is shown in Table 2.

Table 2. Summary of particle size analysis by product classes, Ore 1

Size Product	Fraction	% Weight		Grades % (w/w)						Distribution in assay (%)				
	(mm)	retain.	accum.	Fe	SiO_2	Al_2O_3	P	Mn	LOI	Fe	SiO_2	Al_2O_3	P	Mn
Lump Ore	-38.0+6.35	68.6	68.6	61.0	1.40	0.29	0.10	2.53	10.2	71.2	31.0	22.4	65.7	62.9
Coarse Sinter	-6.35+1.19	10.3	78.9	59.6	1.47	0.35	0.10	2.86	9.92	10.4	4.9	4.0	10.2	10.7
Fine Sinter F.	-1.19+0.15	7.4	86.3	54.8	8.70	0.46	0.10	3.26	9.79	6.9	20.8	3.8	7.2	8.8
Pellet Feed	-0.15+0.037	4.7	91.0	55.0	7.43	0.63	0.10	3.15	10.2	4.4	11.3	3.3	4.8	5.4
-0.037 mm UF	-0.037 UF	4.5	95.5	57.0	4.91	1.01	0.13	3.36	8.24	4.4	7.1	5.1	5.7	5.5
OF	OF	4.5	100.0	35.8	17.0	12.0	0.14	4.12	10.9	2.8	25.0	61.3	6.5	6.8
Calc. Head		100.0		58.8	3.10	0.89	0.10	2.76	10.1	100.0	100.0	100.0	100.0	100.0

The comparison between the chemical composition of feed and sink products for the fine sinter feed, pellet feed and -0.037 mm UF, is shown in Table 3.

Table 3. Comparison between the feed and the sink products in heavy liquid separations, Ore 1

Fraction	Product	% Weight		Grades % (w/w)						Distr. assay (%)		Dist. sample (%)	
		assay	sample	Fe	SiO_2	Al_2O_3	P	Mn	LOI	Fe	SiO_2	Fe	SiO_2
Fine Sinter Feed	sink	92.3	6.8	59.0	1.74	0.65	0.11	3.49	10.9	99.8	18.6	6.9	3.9
	feed	100.0	7.4	54.5	8.65	0.71	0.10	3.25	10.3	100.0	100.0	6.9	20.8
Pellet Feed	sink	94.0	4.4	58.0	2.39	0.58	0.11	3.31	10.9	99.6	30.8	4.4	3.5
	feed	100.0	4.7	54.7	7.30	0.70	0.11	3.14	10.6	100.0	100.0	4.4	11.3
-0.037 mm UF	sink	93.0	4.2	59.1	1.98	0.83	0.13	3.47	8.39	96.3	37.4	4.2	2.7
	feed	100.0	4.5	57.0	4.91	1.01	0.13	3.36	8.24	100.0	100.0	4.4	7.1

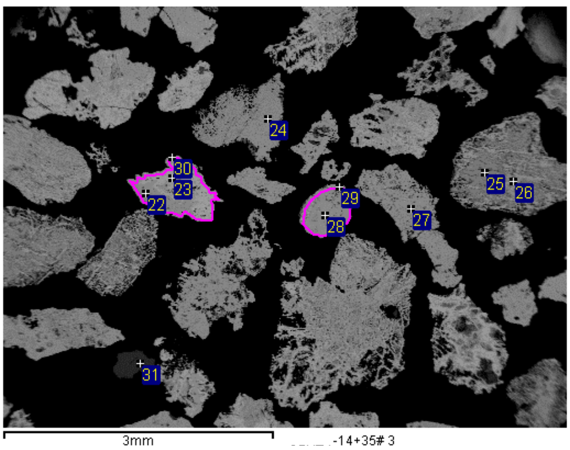
The mineralogical composition (estimated values) of Ore 1, by particle size fraction, is shown in Table 4.

Table 4. Mineralogical composition by particle size fraction, Ore 1

Fraction (mm)	% Weight retained	Minerals % (w/w)					
		Fe oxi-hdrx.	Mn oxides	quartz	clay min.	apatite	others
-38.0+25.4	27.4	93	4	1	tr	1	1
-25.4+12.7	31.2	92	4	1	tr	1	1
-12.7+6.35	9.9	93	4	1	tr	1	1
-6.35+3.36	5.4	90	5	1	tr	1	3
-3.36+1.19	4.9	91	5	2	tr	1	2
-1.19+0.42	4.0	88	5	5	tr	1	1
-0.42+0.15	3.4	80	5	12	tr	1	1
-0.15+0.10	1.3	81	5	11	1	1	2
-0.10+0.074	0.8	84	5	7	1	1	3
-0.074+0.044	1.7	87	5	6	tr	1	1
-0.044+0.037	0.9	86	5	5	tr	1	3
-0.037 UF	4.5	88	5	5	1	1	tr
OF	4.5	45	7	6	39	1	tr
Calculated Head	100.0	89	4	3	2	1	1

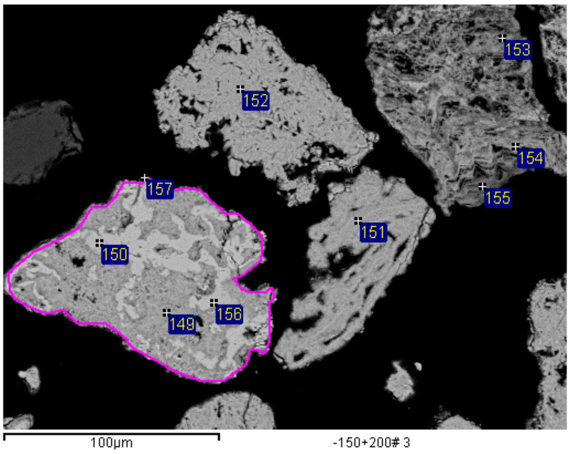
Obs: tr = trace (<0.5%); others = chromite, Al-phosphates, sphalerite.

The main characteristics related to the present minerals, such as mineral associations, porosity and cristallinity of the iron oxi-hydroxydes, may be seen on Figures 1 and 2 (SEM images).



Spectrum	Grades % (w/w) by EDS analysis				
	Fe	SiO_2	Mn	CaO	MgO
22	60.4		0.44		
23	67.0				
24			61.4		
25	42.6	3.50			1.90
26	46.9	1.95		0.36	
27	55.3	0.65	0.83		
28	56.5		1.13		
29	51.2		5.26		
30	62.3		0.69		

Figure 1. Ore 1, fraction -1.19+0.42 mm. Free iron oxi-hydroxides showing high porosity. Manganese oxide is also observed (24).



Spectrum	Grades % (w/w) by EDS analysis				
	Fe	SiO_2	Al_2O_3	P	Mn
149	55.8	1.58			0.59
150	63.4	1.21		0.32	0.56
151	56.5	2.16			0.56
152	56.6	1.52			0.73
153	46.4	2.26	0.68	0.21	0.45
154	49.6	2.49	0.59	0.27	
155	43.3	2.19	1.15		
156	61.3	1.35			0.44
157	57.3	1.63			0.42

Figure 2. Ore 1, fraction -0.10+0.074 mm. Free iron oxi-hydroxides or in microcrystalline aggregations; they show varied grades of Mn (0 to 0.7%) and SiO_2 (1.2 to 2.5%). Traces of Al_2O_3 (0.6-1.2%) and/or P (0.2-0.3%) are also observed.

3.3 Ore 2

The summary of particle size analysis for comminution at -38 mm is shown in table 5.

Table 5. Summary of particle size analysis by product classes, Ore 2

Size product	% Weight		Grades % (w/w)								Distribution in assay (%)				
	retain.	accum.	Fe	SiO_2	Al_2O_3	P	Mn	TiO_2	CaO	LOI	Fe	SiO_2	Al_2O_3	P	Mn
Lump Ore	62.2	62.2	55.0	7.92	2.36	0.05	0.74	...	0.88	10.1	66.9	45.0	37.4	52.4	62.0
Coarse S. Feed	18.3	80.5	52.2	9.42	3.36	0.06	0.71	0.16	1.29	9.90	18.6	15.7	15.7	18.9	17.5
Fine S. Feed	7.5	88.0	49.0	12.6	4.15	0.07	0.76	0.21	1.41	10.7	7.2	8.7	8.0	9.0	7.8
Pellet Feed	2.7	90.7	42.7	18.7	5.18	0.12	0.94	0.53	1.78	10.8	2.3	4.6	3.6	5.8	3.4
-0.037 mm	9.3	100.0	27.8	30.7	15.0	0.08	0.74	0.73	0.99	8.29	5.0	26.0	35.4	13.9	9.3
Calculated Head	100.0		51.2	10.9	3.92	0.05	0.74	...	1.03	9.96	100.0	100.0	100.0	100.0	100.0
Assayed Head			51.9	10.6	3.82	0.06	0.76	0.19	1.11	8.26					

In opposition of Ore 1, Ore 2 didn't present any class of product that achieves the chemical specification regarding SiO_2 grade (<5%), in this comminution situation.
Macroscopic observations of the fractions above 3.36 mm on a stereoscopic microscope indicated that silica occur intimately associated to iron oxi-hydroxides in locked particles. Therefore, the mineral separation assays aiming at the removal of silica bearing minerals didn't work in these fractions, as illustrated on Figures 3 and 4. Textural analysis indicated that silica separation should be carried out just below 3.36 mm (Figures 5 and 6).
So another aliquot of the head sample was grinded below 3.36 mm, followed by wet size screening and mineral separations.

Figure 3. Ore 2, fraction -6.35+3.36 mm. Details of iron oxi-hydroxides and gangue minerals associations.

Figure 4. Ore 2, fraction -6.35+3.36 mm. Once more iron oxi-hydroxides and gangue minerals associations.

Figure 5. Ore 2, fraction -3.36+1.19 mm. The presence of quartz practically in free particles is observed in this fraction.

Figure 6. Ore 2, fraction -3.36+1.19 mm. The same aspect previously observed showing free gangue minerals.

The summary of particle size fraction analysis performed after comminution below 3.36 mm is shown in Table 6.

Table 6. Particle size analysis after comminution below 3.36 mm, Ore 2

Fraction	% Weight		Grades (%)								Distribution in assay (%)				
(mm)	retain.	accum.	Fe	SiO_2	Al_2O_3	P	Mn	TiO_2	CaO	LOI	Fe	SiO_2	Al_2O_3	P	Mn
-3.36+1.19	54.7	54.7	54.5	8.08	2.51	0.05	0.72	0.13	1.05	10.8	57.9	41.3	36.2	48.4	52.3
-1.19+0.42	20.5	75.2	52.7	10.0	3.27	0.06	0.75	0.16	1.13	10.5	20.9	19.2	17.6	20.3	20.6
-0.42+0.15	7.7	82.9	50.2	11.2	3.70	0.06	0.79	0.20	1.23	11.3	7.5	8.0	7.5	8.0	8.1
-0.15+0.037	4.8	87.7	50.5	11.9	2.91	0.08	0.81	0.26	1.37	10.8	4.7	5.4	3.7	7.3	5.3
-0.037 UF	7.8	95.5	44.9	18.8	5.49	0.08	0.80	0.54	1.03	7.66	6.8	13.7	11.3	11.4	8.3
OF	4.5	100.0	24.9	29.7	20.0	0.06	0.89	0.40	0.24	8.04	2.2	12.5	23.7	4.6	5.4
Calc. Head	100.0		51.5	10.7	3.79	0.06	0.75	0.19	1.06	10.4	100.0	100.0	100.0	100.0	100.0
Assayed Head	100.0		51.9	10.6	3.82	0.06	0.76	0.19	1.11	8.26					

The results of magnetic separation carried out in Ore 2, grinded below 3.36 mm, are shown in Figure 7 as SiO_2 against Fe grades.

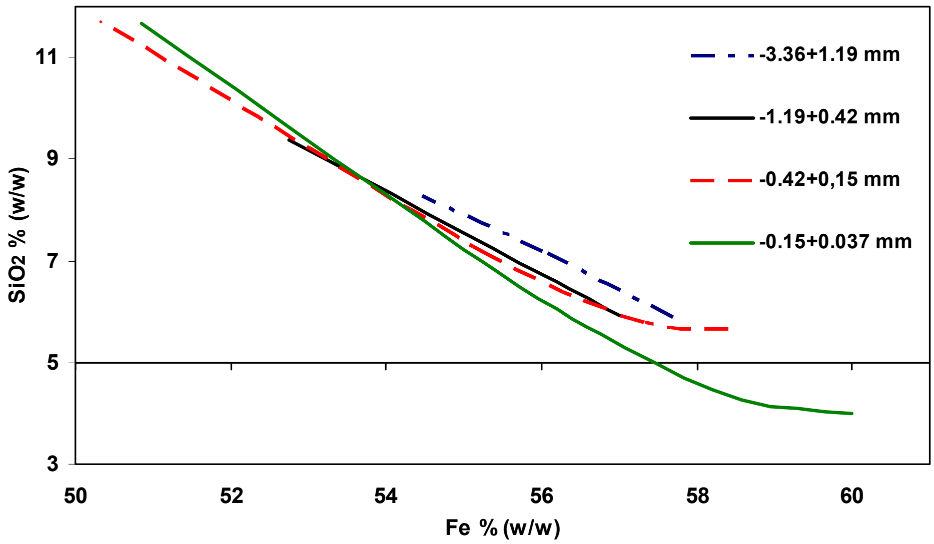


Figure 7. SiO_2 grades against Fe for the mineral separation products of Ore 2 grinded bellow 3.36 mm

Based on the results presented on figure 7, another aliquot of the head sample was grinded bellow 0.15 mm to assess the possibility of obtaining pellet feed with low silica content.

The results of particle size analysis of the ore grinded bellow 0.15 mm are shown in Table 7.

Table 7. Particle size analysis for grinded material below 0.15 mm, Ore 2

Fraction (mm)	% Weight		Grades % (w/w)								Distribution in assay (%)				
	retain.	accum.	Fe	SiO_2	Al_2O_3	P	Mn	TiO_2	CaO	LOI	Fe	SiO_2	Al_2O_3	P	Mn
-0.15+0.074	18.1	18.1	55.9	7.25	1.42	0.05	0.68	0.11	1.11	10.4	19.6	11.8	6.7	15.2	16.1
-0.074+0.037	19.4	37.5	55.7	7.96	1.52	0.06	0.68	0.13	1.07	10.2	20.9	13.9	7.7	18.9	17.5
-0.037 Underflow	30.4	67.9	54.7	10.2	1.60	0.06	0.69	0.25	0.89	8.57	32.2	27.9	12.6	31.1	27.7
Overflow	32.1	100.0	43.9	16.0	8.78	0.07	0.92	0.25	0.66	8.68	27.3	46.3	73.1	34.9	38.8
Calculated Head	100.0		51.6	11.1	3.86	0.06	0.76	0.20	0.89	9.25	100.0	100.0	100.0	100.0	100.0
Assayed Head	100.0		51.9	10.6	3.82	0.06	0.76	0.19	1.11	8.26					

The summary results of the heavy liquid separation for -0.15+0.037 mm fraction are shown in Ttable 8.

Table 8. Mineral separation results for grinded material below 0.15 mm, Ore 2

Fraction (mm)	Product	% Weight		Grades % (w/w)						Distr. assay%		Distr. sample%	
		assay	sample	Fe	SiO_2	Al_2O_3	P	Mn	LOI	Fe	SiO_2	Fe	SiO_2
Total	Sink	95.8	35.9	58.0	4.97	1.20	0.06	0.70	10.5	99.7	63.0	40.4	16.3
-0.15+0.037	Float	4.2	1.6	3.93	65.8	6.98	0.04	0.13	10.2	0.3	37.0	0.1	9.5
	Calc. Fraction	100.0	37.5	55.7	7.53	1.44	0.05	0.68	10.5	100.0	100.0	40.5	25.8

The results of mineral separation, considering both heavy liquid and magnetic separations for all fractions below 0.15 mm on Ore 2, are exposed in Table 9.

Table 9. Mineral separation results for grinded material below 0.15 mm, Ore 2

Fraction (mm)	Product	% Weight assay	% Weight sample	Grades % (w/w) Fe	SiO_2	Al_2O_3	P	Mn	LOI	Distr. assay% Fe	Distr. assay% SiO_2	Distr. sample% Fe	Distr. sample% SiO_2
-0.15+0.074	Mag* Sink	84.6	15.3	59.7	3.71	0.85	0.03	0.74	10.5	90.0	44.7	17.6	5.3
	NMag* Sink	11.5	2.1	47.8	11.9	4.48	0.14	0.42	12.9	9.8	19.4	1.9	2.3
	Float	3.9	0.7	3.72	65.2	5.97	0.04	0.12	11.1	0.3	35.8	0.1	4.2
	Calc. Fraction	100.0	18.1	56.1	7.02	1.46	0.04	0.68	10.8	100.0	100.0	19.6	11.8
	Assayed Fraction			55.9	7.25	1.42	0.05	0.68	10.4				
-0.074+0.037	Mag* Sink	81.7	15.9	60.9	3.46	0.78	0.03	0.77	9.52	87.8	37.7	18.4	5.3
	NMag* Sink	13.8	2.7	48.8	12.0	3.85	0.20	0.46	11.6	11.9	22.0	2.5	3.1
	Float	4.5	0.9	4.10	66.4	7.83	0.04	0.15	9.44	0.3	40.3	0.1	5.6
	Calc. Fraction	100.0	19.4	56.6	7.49	1.52	0.05	0.70	9.80	100.0	100.0	20.9	13.9
	Assayed Fraction			55.7	7.96	1.52	0.06	0.68	10.2				
-0.037 UF	Mag** Sink	48.0	14.6	58.2	5.81	1.18	0.05	0.73	9.60	50.6	28.8	16.3	8.0
	NMag** Sink	46.4	14.1	57.6	6.50	1.41	0.07	0.71	9.57	48.5	31.2	15.6	8.7
	Float	5.6	1.7	9.60	68.9	5.82	0.03	0.17	6.69	1.0	40.0	0.3	11.1
	Calc. Fraction	100.0	30.4	55.2	9.67	1.55	0.06	0.69	9.42	100.0	100.0	32.2	27.9
	Assayed Fraction			54.7	10.2	1.60	0.06	0.69	8.57				
Total -0.15+0.037	Mag* Sink	83.1	31.2	60.2	3.59	0.82	0.03	0.75	10.0	88.8	41.0	36.0	10.6
	NMag* Sink	12.7	4.8	48.3	11.9	4.14	0.17	0.44	12.2	10.9	20.8	4.4	16.3
	Float	4.2	1.6	3.93	65.8	6.98	0.04	0.13	10.2	0.3	38.2	0.1	9.5
	Calc. Fraction	100.0	37.5	56.4	7.27	1.50	0.05	0.69	10.3	100.0	100.0	40.5	36.3

*Obs: * Frantz magnetic separator; ** WHIMS magnetic separator*

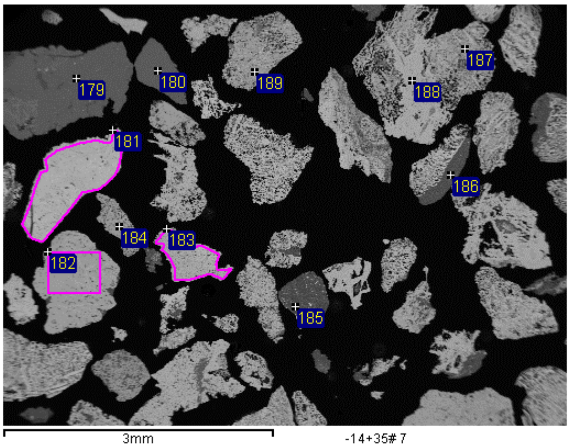
The mineralogical composition (estimated values) of Ore 2, by particle size fraction, is shown in Table 10.

Table 10. Mineralogical composition by particle size fraction, Ore 2

Fraction (mm)	% Weight retained	Minerals % (w/w) Fe oxi-hdrx.	clay min.	quartz	calcite	others
-0.15+0.074	18.1	85	5	6	2	2
-0.074+0.037	19.4	85	5	6	2	2
-0.037 Underflow	30.4	84	5	8	1	1
Overflow	32.1	63	31	5	1	tr
Calculated Head	100.0	78	13	6	1	...

Obs: tr = (…) unavailable information; trace (<0.5%); others = titanium oxide, manganese oxide and apatite.

The main characteristics related to the present minerals, such as mineral associations, porosity and crystallinity of the iron oxi-hydroxydes, may be seen on Figures 8 to 10 (SEM images).



Spectrum	Grades % (w/w) by EDS analysis						
	Fe	SiO_2	Al_2O_3	Mn	CaO	MgO	K_2O
179	0.40	4.49	3.37		48.5	0.80	0.80
180					54.0		
181	60.5	1.49					
182	52.6	3.07		0.44	0.37	1.15	
183	57.3	3.19	1.72				0.26
184	54.6	3.35				1.05	
185		85.7					
186	2.11	34.8	28.1				6.45
187	38.8	1.94				0.64	
188	49.7	0.66		0.37			
189	49.7	2.51		5.99	0.44	1.56	

Figure 8. Ore 2, fraction -1.19+0.42 mm. Common view. Iron oxi-hydroxides with high porosity, free or locked with mica (186) and/or quartz. Minute inclusions of these two minerals are also observed into iron oxi-hydroxides.

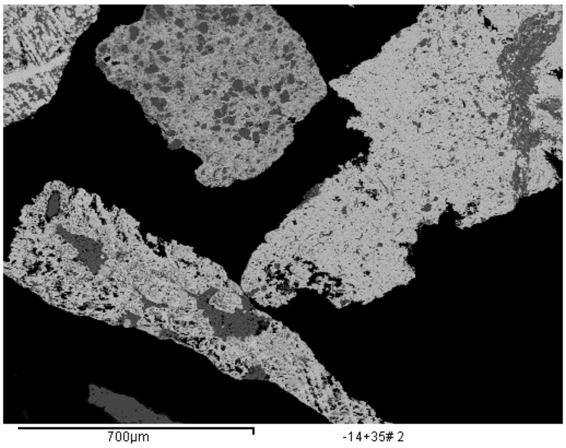
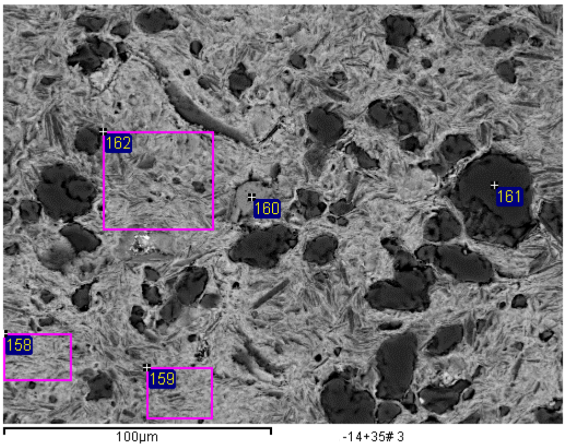


Figure 9. Ore 2, fraction -1.19+0.42 mm. Iron oxi-hydroxides with quartz inclusions (grey regions) of variable dimensions, achieving up to 150-200 μm



Spectrum	Grades % (w/w) by EDS analysis				
	Fe	SiO_2	Al_2O_3	TiO_2	K_2O
158	48.2	7.78	6.50		1.08
159	45.4	9.52	8.21		1.27
160	1.55	1.50	1.01	91.6	0.24
161	0.72	83.7			
162	43.5	11.7	9.10		1.42

Figure 10. Ore 2, fraction -1.19+0.42 mm. Detail of iron hydroxide and clay minerals aggregate (158,159,162), with quartz inclusions (161) up to 25 μm and titanium oxides (160) with about 10 μm.

A comparison of the main characteristics observed for the two ore samples may be visualized in Table 11.

Table 11. Comparison between the main characteristics of the studied samples

	Ore 1	Ore 2
Chemical composition % (w/w - assayed grades)		
Fe	59.4	51.9
SiO_2	2.86	10.6
Al_2O_3	0.88	3.82
P	0.09	0.06
Mn	2.84	0.76
TiO_2	0.04	0.19
CaO	0.05	1.11
MgO	0.04	0.37
Na_2O	0.05	0.13
K_2O	0.12	0.72
LOI	10.3	8.26
Mineralogical composition % (w/w)		
iron oxi-hydroxides	89	78
clay minerals	2	13
quartz	3	6
manganese oxide	4	tr
apatite	1	tr
calcite		1
others	1	1
Phosphorus partition (%) +0.037 mm		
iron oxi-hydroxides	44	57
apatite	56	43
Iron oxi-hydroxides characteristics		
Liberation size	-38.0 mm	-0.15 mm
Iron recovery (%) +0.037 mm (SiO_2 < 5%)	93	40
-0.037 mm underflow % (w/w)	4.5	30.4
Slimes % (w/w)	4.5	32.1
Fe losses in slimes %	2.8	27

Obs: tr = trace (<0.5%); others = chromite, Al-phosphate, sphalerite (Am.1), titanium oxide (Am. 2)

4 DISCUSSION

Based on the results of chemical analysis (X-ray fluorescence) and mineralogical analysis (X-ray diffraction and scanning electron microscopy) of the mineral separation products, the relevant characteristics to the mineral dressing can be established.

Ore 1 has a higher Fe grade, with 59.4% against 51.9% in Ore 2, which shows a higher grade of SiO_2 (10.6%) regarding Ore 1 (2.86%). The Al_2O_3 grade in Ore 2 corresponds to 3.82% and in Ore 1 it is 0.88%. The P grades are 0.09 and 0.06%, respectively for Samples 1 and 2. The Mn grade is higher in Ore 1 (2.84%) than in Ore 2 (0.76%). Ore 2 still shows grades of 1.11% of CaO, 0.72% of K_2O, 0.37% of MgO, 0.19% of TiO_2 and 0.13% of Na_2O; in Ore 1 all these grades are situated between 0.04 and 0.05%, in exception of K_2O which is 0.12%. The loss on ignition grade is higher in Ore 1 (10.3%) than in Ore 2 (8.26%).

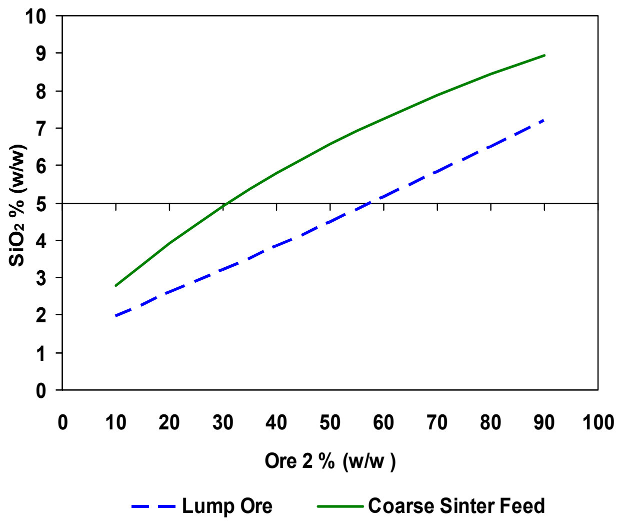
Both samples present basically the same mineralogical constituents, with subtle variations in its relative. The samples are composed essentially by iron oxi-hydroxides (mainly goethite and in minor proportions hematite; a small quantity of magnetite occurs in Ore 2), clay minerals (vermiculite, micas) and quartz, such as manganese oxides, apatite, calcite and others (titanium oxide, chromite, sphalerite and Al-phosphate).

In Ore 1 a higher proportion of iron oxi-hydroxides is observed (89%, against 78% in Ore 2) and smaller proportion of clay minerals (2% against 13% in Ore 2). Among the iron oxi-hydroxides the hydrated phase (essentially goethite) predominates and occurs as porous aggregates. Hematite occurs though in small proportion usually as compact aggregates (less porous) or in preserved nucleus.
The quartz proportion in Ore 2 corresponds to 6%, while in Ore 1 it is 3%. The content of manganese oxides in Ore 1 is 4% and traces for Ore 2; apatite is about 1% in Ore 1 and also traces in Ore 2. Calcite was observed only in Ore 2 (around 1%); other minerals like chromite, Al-phosphates, sphalerite (Ore 1) and titanium oxide correspond to 1% in both samples.
Besides more evident porosity, Ore 2 contains calcite, clay minerals and quartz frequently associated with iron oxi-hydroxides, as inclusions inside of the porous aggregates. In Ore 1 this association exists at a lower level. Regarding the phosphorus content above 0.037 mm, apatite carries 56% of the P content in Ore 1 and 43% for Ore 2; the remaining portion is essentially associated to goethite.
For Ore 1, lump and coarse sinter feed products with silica grades bellow 5% (w/w) can be produced by comminution under 38 mm. Therefore, lump ore corresponds to 69% weight and 61% of Fe (grade in assay; 71% of total Fe in the sample) and 1.4% of SiO_2. Coarse sinter feed corresponds to 10% weight, and 60% of Fe (grade in assay; 10% of total Fe in the sample) and 1.5% of SiO_2. Mineral separation assays indicate that further processing allow to obtain also fine sinter feed and pellet feed products under required specifications. Fine sinter feed corresponds to 7% weight and 59% of Fe (grade in assay; 7% of total Fe in the sample) and 1.5% of SiO_2. Pellet feed corresponds to 4% weight and 58% of Fe (grade in assay; 4% of total Fe in the sample) and 2% of SiO_2. The -0.037 mm underflow correspond to 4.5% weight and 57% of Fe (grade in assay; 4.4% of total Fe in the sample) and 4.9% of SiO_2, so it's also suitable for the required specifications. The Fe global recovery considering the fraction -0.037 mm underflow as a product is 97%, or 93% not considering the utilization of this fraction.
For Ore 2, the liberation of the iron oxi-hydroxides occurs only below 0.15 mm, which was verified after attempting to obtain coarse products. Thus the production of pellet feed demands further mineral concentration. Considering the grinding bellow 0.15 mm, heavy liquids and magnetic separation (fraction size above 0.037 mm) allow to attain a product presenting 31% weight with 60% of Fe (grade in assay; 36% of total Fe in the sample) and 3.6% of SiO_2. Moreover, -0.037 mm underflow represents 15% weight with 58% of Fe (grade in assay; 4.4% of total Fe in the sample) and 5.8% of SiO_2.

5 CONCLUSIONS

The results obtained with this study indicate that, for Ore 1, lump and coarse sinter feed products with silica grades bellow 5% (w/w) can be produced just by comminution under 38 mm and classification; the other products (fine sinter feed and pellet feed) have to be concentrated to achieve the required specifications.
For Ore 2, the liberation of the iron oxi-hydroxides occurs only below 0.15 mm, only pellet feed is possible to be obtained. In this case, concentration steps must be done.
Considering the required specifications, studies of flotation and/or magnetic separations shall be evaluated to obtain fine sinter feed and pellet feed in Ore 1 and pellet feed in Ore 2, aiming to define a process flow sheet for the mineral dressing.

Supposing the beneficiation of both samples mixed and aiming to maximize the Ore 2 contribution, the obtained results indicate that the production of lump ore and coarse sinter feed is possible, with silica grades below 5%. In this case it can be achieved just by comminuting the ore bellow 38 mm and composing them in relative proportions of 70% of Ore 1 and 30% of Ore 2, as evidenced in Figure 11.



BLENDED ORE (70% Ore 1 + 30% Ore 2)			
Products	% (w/w)	Grades % (w/w)	
		Fe	SiO_2
Final products			
Lump Ore	66.7	59.3	3.22
Coarse Sinter Feed	12.7	56.4	4.91
For further processing			
Fine Sinter Feed	7.4	53.1	9.88
Pellet Feed	4.1	52.6	9.65
-0,037 mm	9.1	40.7	17.0
Calc. Head	100.0	56.5	5.45

Figure 11. SiO_2 grades for blended ore grinded bellow 38 mm (related to added proportion of Ore 2).

On the other hand, for fine sinter feed and pellet feed obtention, concentration steps are necessary for any blending condition.

Acknowledgments

The authors are grateful to Votorantim Group for the authorization to publish the data present in this paper.

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