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Mineralogical Characterisation of Iron Ore Tailings by Integrated Mineral Analyser

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Abstract— **Ore technological characterisation consists of a sequence of operations used in obtaining essential information used for route scaling and improvements on overall yield in a process, comprising, within the mineralogical characterisation stage, the fundamental and textural basis for technical and economic feasibility of a mineral project. Among the various mineralogical characterisation techniques that currently exist, there is a special interest in integrated mineral analysers, which are instruments used to perform quick and precise automatic qualitative and quantitative mineralogical analysis. The produced results were validated through the characterisation of tailing samples from the flotation and magnetic separation of iron ore. Qualitatively, the tailing samples revealed a mineralogy composed essentially by quartz, hematite, goethite and magnetite. Quantitatively, higher volumetric fractions in quartz and lower volumetric fractions in iron oxides/hydroxides and accessory minerals were verified on the flotation and coarse magnetic separation tailing samples, while fine magnetic separation tailings samples presented higher proportions in iron oxides/hydroxides and lower proportions of quartz. The results were all validated by previous studies undertaken through complementary techniques.**

Index Terms— **Mineralogical Characterisation, Integrated Mineral Analyser, Iron ore tailings.**

I. INTRODUCTION

The Brazilian mining industry generates an extraordinary amount of tailings, whose proper disposal is one of the main constraints to the viability of mining activity and in the generation of environmental impacts. In this context, tailings are materials resulting from processing, which may have significant levels of iron, due to the low release of gangue minerals a mineral of interest, whose viability is compromised by the absence of technological processes that enable its processing [1,2,3,4]. According to the industrial process and the ore processed, the tailings generated acquire different physical, chemical and mineralogical characteristics [5]. The technological characterisation of the product is critical in order to allow an evaluation the characteristics and properties relevant for reuse in various applications. Aiming at the sustainability, the recycling of tailings is a very important environmental management tool, however, a successful research and development of new material from tailings can be a complex, multidisciplinary task [6]. Studies on the use of iron ore tailings have been made in terms of their potential applications in the mining sector through its use as a low-grade ore and ceramic industry, partly replacement of matter material used [7,4].

The samples selected for this study are tailings iron ore processing of Mining industry located in Brazil. Based on grain size and source process, these tailings were classified as floatation tailings, coarse tailings of magnetic concentration and fine tailings of magnetic concentration.

Iron mineralization samples were selected from the Iron-Manganesífero District Urandi-Caetité-Licinio de Almeida, associated with the meta-volcano-sedimentary Caetité-Licinio de Almeida, Paleoproterozoic unit of the southern sector of the Sierra Northern Stranglethorn, in São Craton Francisco [8,9]. Regionally, the sequence is comprised of itabirites, marbles (rich in calcite, dolomite and manganese), calcium-silicate rocks, metabasalts, aluminous schists, quartzites and grunerita-cummingtonite schist, subordinate to gneiss. This region host 35 mines with manganese and of iron. The iron ore itself is consisteds of lenticular bodies of powdery hematite associated with shales interspersed with itabirites at levels enriched in magnetite due to hydrothermal alteration [10].

II. MATERIALS AND METHODS

The mineralogical characterisation of tailings of iron ore samples used an integrated mineral analyser known as TIMA-MIRA. The TIMA-MIRA system was designed specifically for the mining industry and enables fast quantitative mineralogical analyzes of rocks, ores, concentrates, tailings, leach residues and foundry products. The system consists of a software scan control and minerals data analysis, called TIMA, and uses a SEM hardware / EGF-EDX integrated, commercially known as MIRA, consisting of a scanning electron microscope with electron gun by field emission (FEG - field Emisson Gun), together with two energy dispersive detectors using characteristic X-rays [11].

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The tailings (floatation tailings, coarse tailings of magnetic concentration and fine tailings of magnetic concentration) were fractionated in particle sizes >0.106 mm, >0.075mm, >0.044mm and <0.044 mm. These samples were characterized previously by particle size, in qualitative terms by X-ray diffraction and quantitative terms by optical microscopy (manual counting particles), aiming, studies of its use as additives in the concrete blocks manufacture and industrial ceramics production [4,5].

III. Results and Discussion

In mineralogical terms, the quantitative composition of the respective particle sizes of floatation tailings, coarse tailings of magnetic concentration and fine tailings of magnetic concentration were obtained. And in textual terms, the main textures associated with the main majority mineral species were evaluated.

3.1. Qualitative Mineralogical Composition

For all selected samples field images were obtained by acquiring data in automated mineralogy systems, corresponding to the distribution maps of mineral phases and showing the mineralogical composition of the sample in qualitative terms. Figure 1 shows the mineralogical images of samples of particle sizes of the tailings floatation, in which there was a predominance of quartz mineral in the ranges >0.106 mm, >0.075 mm, >0.044 mm and in the range <0.044 mm quartz and hematite minerals .

Figure 2 shows the mineralogical images of respective particle sizes of the coarse tailings of magnetic concentration, in which are predominantly quartz mineral in the ranges >0.106 mm >0.075 mm to >0.044 mm and quartz and hematite and magnetite minerals in range <0.044 mm. Figure 3 shows the mineralogical images of respective particle sizes of fine tailings of magnetic concentration, which shows the predominance of quartz and hematite minerals, in addition to the substantial increase of magnetite and goethite in all particle sizes.

The mineralogy of the three types of tailings included still accessory minerals such as pyrolusite, albite, cromoferrita, biotite, muscovite, tourmaline, kaolinite, magnesiogedrita, bannisterita, ankerite and dolomite, in addition to the main mineral assemblage consisting of quartz, hematite, goethite and magnetite. All these minerals are related to rocks in the regional geological context regional, where there is a blend of itabirites, schist, marble and metabasalts, and subordinates to gneiss (Borges et al, 2015). In general terms, as the tailings are of iron processing, it is natural, occurrence of gangue minerals such as silicates and carbonates, and ore mineral (iron oxides and hydroxides) in all considered groups.

Qualitative analysis results of iron ore tailings obtained by automated mineralogy system are in agreement with results obtained in earlier studies using X ray diffraction [4]. In X-ray diffraction were identified essentially the quartz, hematite and kaolinite minerals. As well the results produced by analysis in automated mineralogy systems, and using X-ray diffraction, quartz is the main mineralogical component of the analysed tailings.

3.2. Quantitative Mineralogical Composition

Quantitative mineralogical compositions were obtained through mineral mass report analysis provided by automated mineralogy system software. The volume fractions were calculated from the number of pixels identified for each phase.

Table I presents the mineralogical composition, in quantitative terms, by particle sizes of the floatation tailings. The range >0.106 mm records the largest amount of quartz (96.10%) and minor amounts of iron oxides and hydroxides (3.27%) and other phases (0.62%), which include the remaining and not classified. Unlike in the range <0044 mm has the smaller volume of quartz (67.78%) and larger volumes of oxides and hydroxides of iron (27.02%) and other phases (5.18%). In ranges > 0.075 mm and > 0.044 mm, there is an intermediate value between the two extremes described. Table II presents the mineralogical composition, in quantitative terms, by particle sizes of coarse tailings of magnetic concentration. The range >0.106 mm records the largest amount of quartz (94.36%) and minor amounts of iron oxides and hydroxides (4.34%) and other phases (1.30%), which include the remaining and not classified similar values obtained in the range >0.075 mm, respectively, 93.82%, 4.64% and 1.55%. in opposition in the range <0044 mm has the smaller volume of quartz (64.53%) and larger volumes of oxides and hydroxides of iron (28.58%) and other phases (6.89%).

Noted in Tables I and II, tendency of decrease in the percentage of quartz, and increased percentage of oxides, iron hydroxides and other mineral phases with decreasing particle size. Table III presents the mineralogical composition, in quantitative terms, by particle sizes of fine tailings of magnetic concentration. As well the samples of the floatation tailings and coarse magnetic separation, in the >0.106 mm range records the smaller volume of other phases (2.14%), while the range <0.044 mm exhibits the largest volume (14.55%). However, the volume of iron oxides and hydroxides is relatively high in all particle sizes of fine tailings of magnetic concentration, not obeying the behavior identified in floatation tailings and of coarse tailings of magnetic concentration.

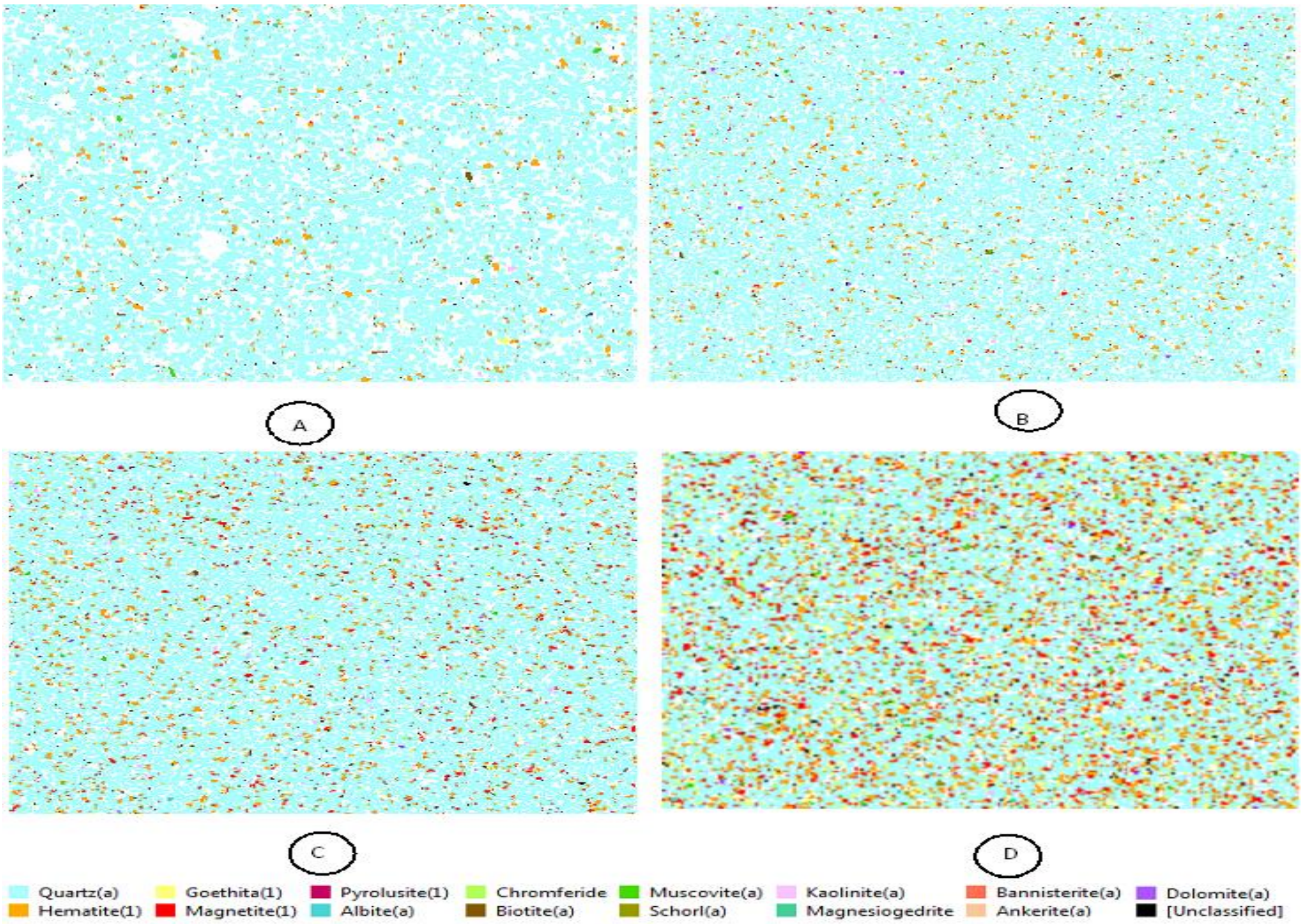

Figure 1. Mineralogical pictures of floatation tailings obtained by analysis in TIMA-MIRA system for particle sizes (A) >0.106 mm, (B) >0.075 mm, (C) >0.044 mm e (D) <0.044 mm.

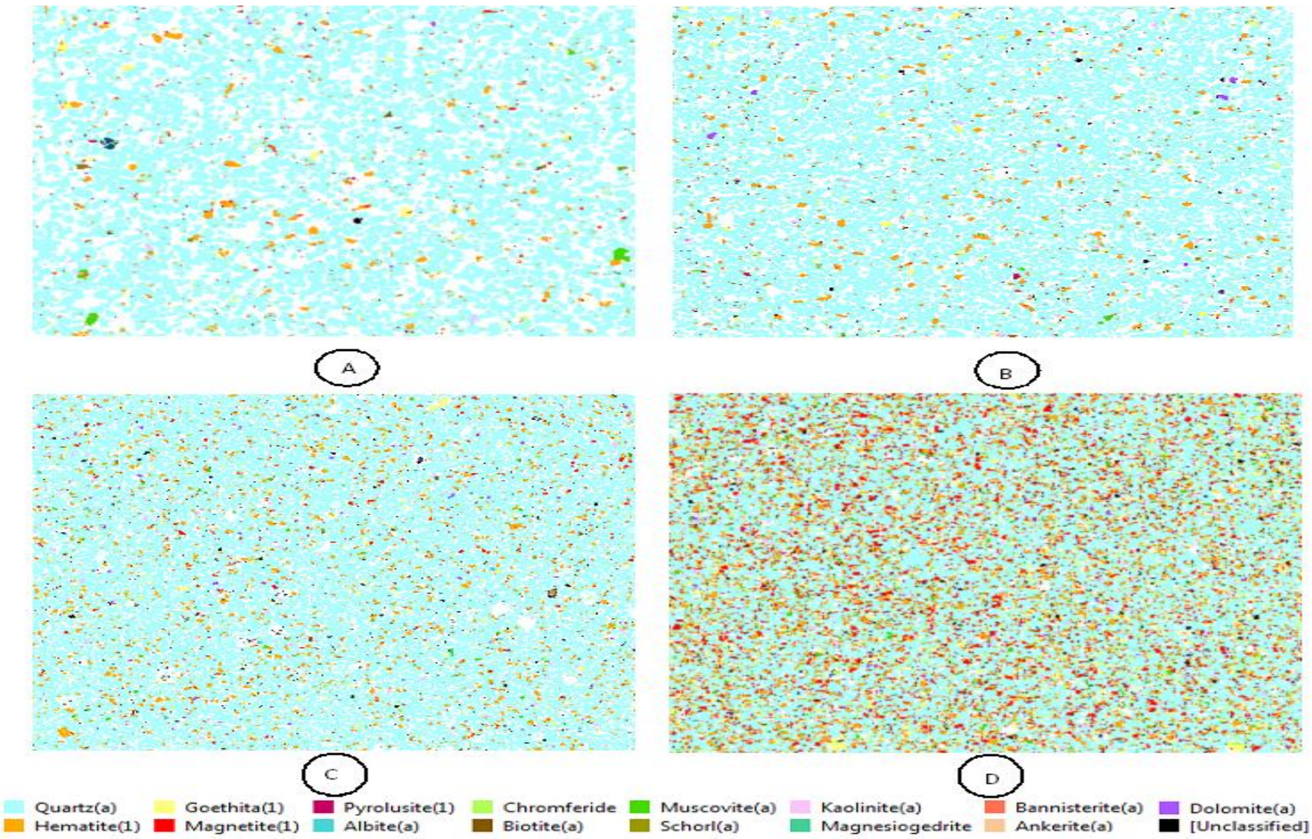

Figure 2. Mineralogical pictures of coarse tailings of magnetic concentration obtained by analysis in TIMA-MIRA system for particle sizes (A) >0.106 mm, (B) >0.075 mm, (C) >0.044 mm e (D) <0.044 mm.

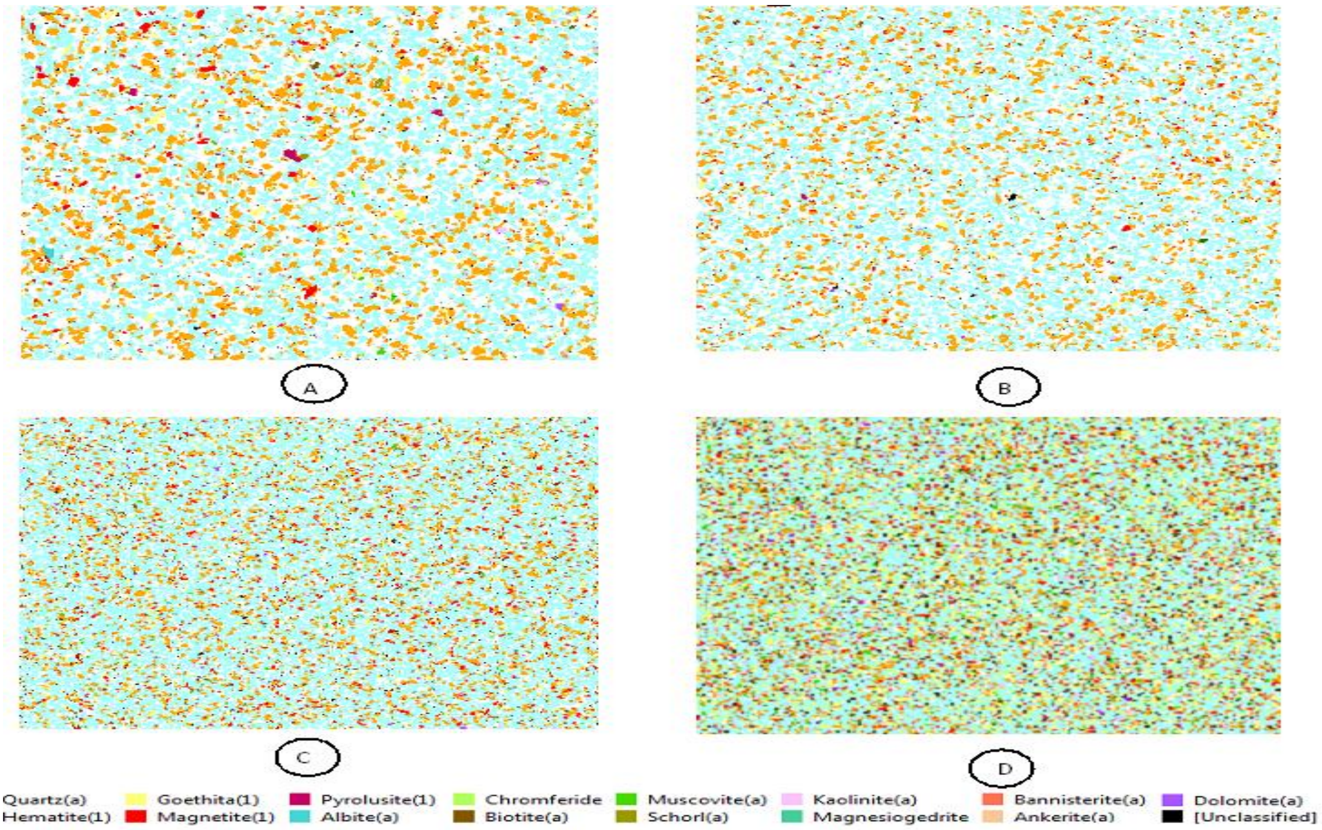

Figure 3. Mineralogical pictures of fine tailings of magnetic concentration obtained by analysis in TIMA-MIRA system for particle sizes (A) >0.106 mm, (B) >0.075 mm, (C) >0.044 mm e (D) <0.044 mm.

Table I. Modal analysis of the particle sizes of the floatation tailings obtained by analysis in TIMA-MIRA.

Minerals	Percentage in volume by particle size.			
	>0.106 mm	>0.075 mm	>0.044 mm	<0.044 mm
Quartz	96.1	94.09	89.52	67.78
Hematite	2.53	3.79	5.59	13.46
Goethite	0.42	0.48	0.99	6.97
Magnetite	0.32	0.78	2.17	5.59
Kaolinite	<0.20	0.21	0.44	1.11
Muscovite	<0.20	<0.20	0.26	0.65
Biotite	<0.20	<0.20	<0.20	0.29
Ferrokarpholith	<0.20	<0.20	<0.20	0.26
Cromoferrite	<0.20	<0.20	<0.20	0.20
Bannisterita	<0.20	<0.20	<0.20	0.20
Others	0.45	0.46	0.65	0.87
Unclassified	0.17	0.2	0.39	1.6

Table II. Modal analysis of the particle sizes of coarse tailings of magnetic concentration obtained by analysis in TIMA-MIRA.

Minerals	Percentage in volume by particle size.			
	>0.106 mm	>0.075 mm	>0.044 mm	<0.044 mm
Quartz	94.36	93.82	89.15	64.53
Hematite	2.79	3.65	5.75	14.22
Goethita	1.07	0.99	1.55	6.4
Magnetite	0.48	<0.20	0.9	7.96
Kaolinite	0.33	0.44	0.75	1.31
Muscovite	<0.20	<0.20	0.36	1.02
Biotite	<0.20	<0.20	<0.20	0.20
Cromoferrite	<0.20	<0.20	<0.20	0.41
Others	0.68	0.81	0.85	1.52
Unclassified	0.29	0.30	0.71	2.43

Table III. Modal analysis of the particle sizes of fine tailings of magnetic concentration obtained by analysis in TIMA-MIRA.

Minerals	Percentage in volume by particle size			
	>0.106 mm	>0.075 mm	>0.044 mm	<0.044 mm
Quartz	64.22	70.37	70.59	54.88
Hematite	27.23	23.82	17.75	12.35
Goethita	3.33	2.49	4.14	15.31
Magnetite	3.07	1.58	3.68	3.91
Kaolinite	0.31	0.32	0.82	2.1
Muscovite	0.23	<0.20	0.61	1.75
Biotite	<0.20	<0.20	0.44	1.41
Ferrokarpholith	<0.20	<0.20	0.27	1.04
Cromoferrite	<0.20	<0.20	0.21	1.32
Bannisterite	<0.20	<0.20	<0.20	0.78
Tourmaline	<0.20	<0.20	<0.20	0.37
Pyrolusite	0.24	<0.20	<0.20	<0.20
Others	0.81	0.96	0.72	0.96
Unclassified	0.55	0.46	0.76	4.82

From Table III, also demonstrates that there is a substantial increase of goethite and magnetite minerals in the composition of the iron oxy-hydroxides, in relation to other tailings. In mineral processing, the flow that relates the mineral concentration methods, the flotation and magnetic separation directly reflected in the particle size and differences in percentages of minerals that make up the waste tailings produced (Oliveira, 2013). In previous works, the particle size characterisation was made by sieving down to 44μm and below the values by cyclosizer.

The floatation tailings were between 105μm and 40μm, centered at 75μm. The tailings from the magnetic separation were between 300μm and 40μm, centered a 105μm. The finer tailings from magnetic separation showed all particles to be smaller than 53μm, with 60% below 5μm (Silva et al, 2014). The results of mineralogical quantification obtained in automated mineralogy system for waste, show variations in the volume percentage of the mineralogical assembly depending on the type of tailings and, consequently, due to the particle size (Oliveira, 2013). Therefore, mineralogical compositions in qualitative and quantitative terms, established a direct relationship with the grain size, confirming the pattern identified in the tailings samples. In the context described here, the flotation is the most efficient process in the ore concentration, in function of their selectivity, the tailings produced by this method had the highest overall volume fractions of quartz and lower global volume fractions of oxides and hydroxides. In the magnetic separation process it was found that the behavior of the global volume fractions of identified minerals, established a direct relationship with the particle size of the tailings, since the process was the same for a fraction of coarse and fine. For coarse tailings of magnetic concentration , the percentages are similar to those obtained in the floatation tailings, as the grain size distributions of both tailings were similar, resulting in good performance of the process of concentration of iron ore. For fine tailings of magnetic concentration, however, quartz volume fractions were recorded and fractions of volume of iron oxides and hydroxides, respectively lower and higher than the volume fractions obtained for the other two types of tailings. The fine tailings of magnetic concentration have fine granulometry, which was found to be lower than the other tailings, therefore in its range, and with a greater amount of iron oxides and hydroxides and other mineral phases.

Tables IV, V and VI show the results of quantitative mineralogical composition obtained by optical microscopy (manual counting particles) for floatation tailings, coarse tailings of magnetic concentration and fine tailings of magnetic concentration..

Table IV- Quantitative mineralogical composition obtained by optical microscopy (manual counting particles) for floatation tailings.

Minerais	Percentage in volume by particle size.			
	>0.106 mm	>0.075 mm	>0.044 mm	<0.044 mm
Hematite	11.37	3.34	9.34	2.15
Goethite	0.29	0.00	0.00	0.00
Quartz	86.47	95.73	88.67	97.31
Others	1.87	0.93	1.99	0.54

Table V- Quantitative mineralogical composition obtained by optical microscopy (manual counting particles) for coarse tailings of magnetic concentration.

Minerais	Percentage in volume by particle size.			
	>0.106 mm	>0.075 mm	>0.044 mm	-0.044 mm
Hematite	2.28	4.13	9.83	31.24
Goethite	0.36	0.27	0.57	3.35
Quartz	95.80	95.21	84.5	59.97
Others	0.55	0.40	5.10	6.96

Table VI- Quantitative mineralogical composition obtained by optical microscopy (manual counting particles) for fine tailings of magnetic concentration.

Minerais	**Percentage in volume by particle size.**			
	>0.106 mm	>0.075 mm	>0.044 mm	-0.044 mm
Hematite	32.28	18.82	21.9	13.06
Goethite	1.57	2.80	1.41	10.42
Magnetite	0.59	5.60	0.00	0.00
Quartz	64.17	70.76	69.61	69.71
Others	1.49	1.40	7.07	6.41

Figures 4, 5 and 6 show comparisons between methods executed. The differences in the proportions of volume fractions between the results obtained from analysis of mineralogy automated system and method of optical microscopy (manual counting particles) are acceptable because both methods admit confidence levels for all measured values. The resolution used for data acquisition was set to 10 micrometres. Each point of the selected analysis area determined their chemical composition and was properly associated with the corresponding mineral. Subsequently, calculations to comprise the total volume fraction of the mineral in question, regardless of its occurrence condition associated with particles of other minerals in the grain form, including or in small compositional variations, resulting sometimes in super estimated values of the real amount of free particles in the optical microscopy (manual counting particles). In case of discrepancies, the results obtained by both techniques, for the sample of the range of particle size <0.044 mm tailings floatation, the error is possibly linked to inaccuracies in the points count optical microscopy (manual counting particles), and in the range considered the fine particle size.

In addition to providing more accurate results with respect to measuring the mineralogical assembly, the analysis in automated mineralogy systems in study performed a complete scan of the polished section with a resolution of 10 micrometres in approximately two hours' time less than that required in other techniques, such as have done using optical microscopy (manual counting particles), considering the resolution used.

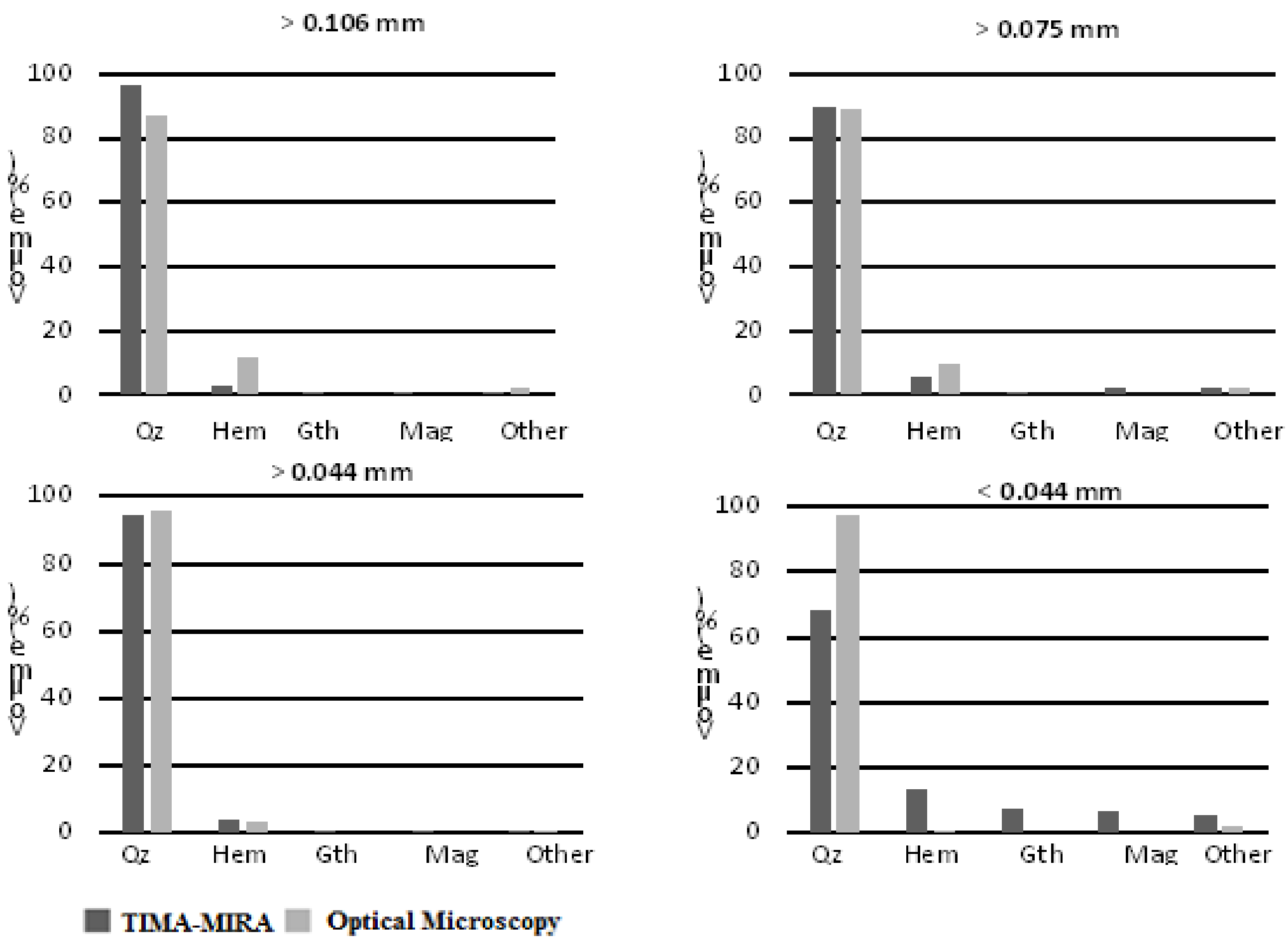

Figure 4. Comparison of the results obtained by optical microscopy (manual counting particles) and the automated mineralogy system for the floatation tailings, where Qz is Quartz, Hem is hematite, Gth is goethite e Mag is magnetite.

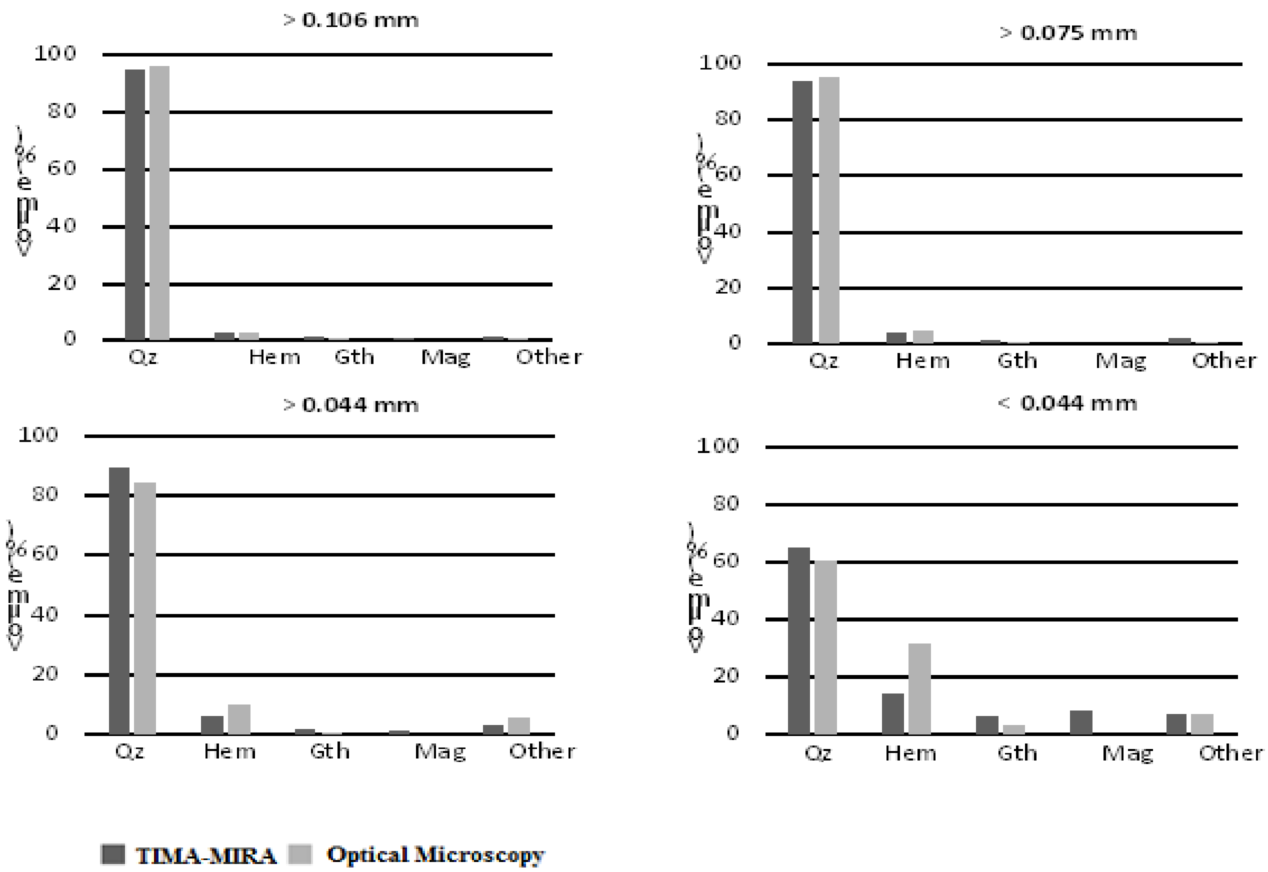

Figure 5. Comparison of the results obtained by optical microscopy (manual counting particles) and the automated mineralogy system for the coarse tailings of magnetic concentration, where Qz is Quartz, Hem is hematite, Gth is goethite e Mag is magnetite.

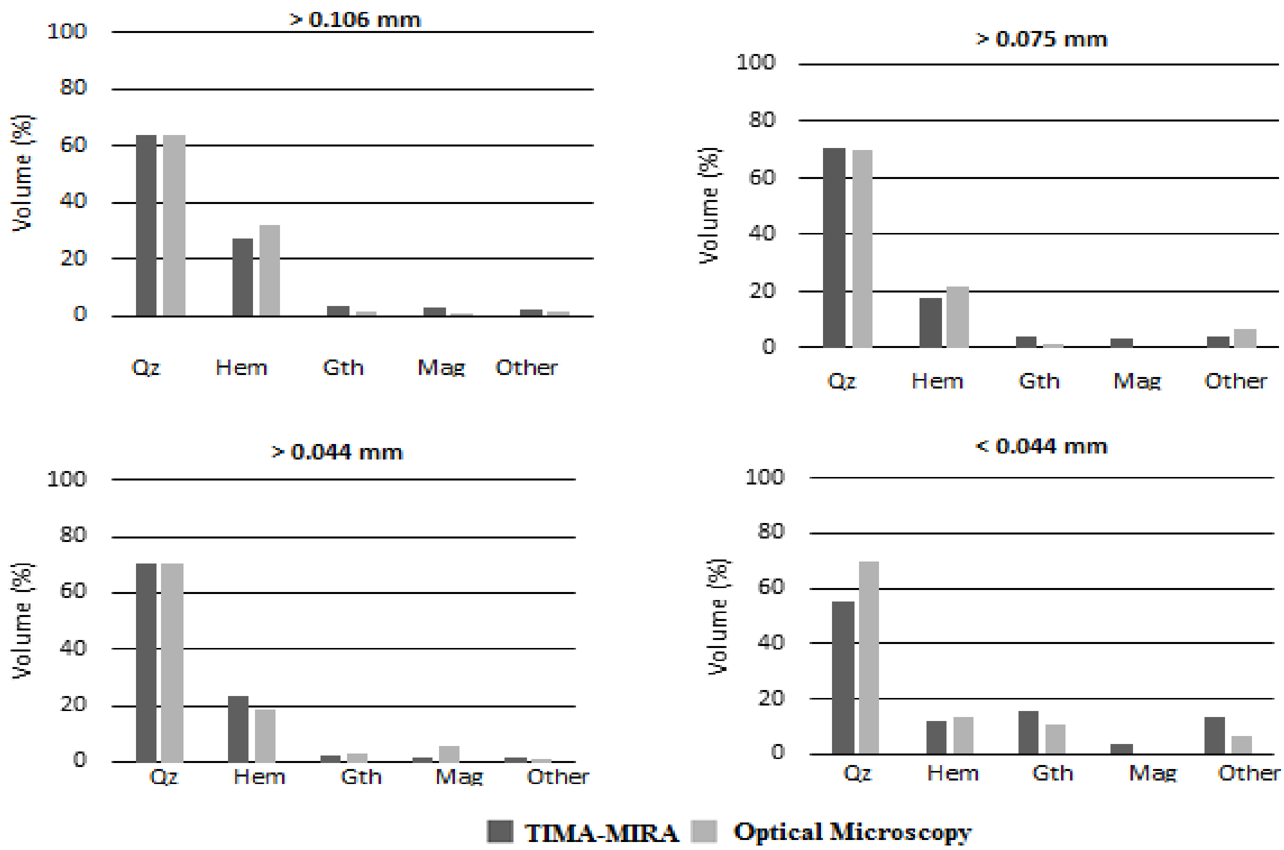

Figure 6. Comparison of the results obtained by optical microscopy (manual counting particles) and the automated mineralogy system for the fine tailings of magnetic concentration, where Qz is Quartz, Hem is hematite, Gth is goethite e Mag is magnetite.

IV. Conclusion

This work demonstrates how technological characterisations of minerals includes mineralogy stage processes reveal some of, one of the most important information needed to make full use of a mineral resources and sizing of manufacturing process routes. As well in regards to the main product of mineral processing, tailings generated in ore concentration can also be characterized in order to show information relevant to their use, both for its processing, in the form of low-grade ore, or in its reuse in other industrial sectors. Currently, mining tailings are stored in dams and generate large environmental impacts. The allocations of these tailings to the diverse applications will help to minimize environmental problems associated with them. In this context, as seen in the literature, the use of automated mineralogy technology systems is increasingly recurrent in the mining industry, essentially, in the mineralogical characterisation of ore and tailings, which includes studies of mineral release, the fully automated analysis and its potential in the statistical generation of quantitative data, resulting in substantial benefits of economic and scientific order.

Through automated mineralogy systems it was possible to both qualify and quantify main iron oxides and hydroxides (hematite, magnetite and goethite), besides other minerals (pyrolusite, kaolinite, albite, biotite, muscovite, cromoferrita, ferrocarfolita, bannisterita, magnesiogedrita, tourmaline , ankerite and dolomite), which were present in the tailings. The floatation tailings and the coarse tailings of magnetic concentration showed the highest volume fractions of quartz, while fine tailings of magnetic concentration had high volume fractions of iron oxy-hydroxides and other mineral species. These differences in mineralogical composition of the tailings are the result of the flow concentration processes, which further explains the tendency of increased volume fractions of iron oxy-hydroxides and decreasing the volume fraction of quartz with decreasing particle size of the same type tailings. The results of this work are in accordance with results obtained in previous works and were acquired in a period of rapid time to resolution used.

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References

[1] WOLF, A.P., COSTA, G.M., DUTRA, F.C. (2011). A comparative study of ultra-fines iron ore tailings from brazil – *Mineral Processing & Extrative Metal*.

[2] SANTOS D. A. M., CURI A., SILVA J. M.(2010). Técnicas para a disposição de rejeitos de minério de ferro. In: 6º CBMina, Belo Horizonte, Anais, 1: 100-105.

[3] OLIVEIRA, T. M. (2013). Caracterização de Misturas de Rejeitos de Minério de Ferro Melhoradas com Adição de Cimento com Vistas à Aplicação em Estradas e Aterros. Departamento de Engenharia Civil, Universidade Federal de Viçosa, *Dissertação de Mestrado*, 71p.

[4] F. L. DA SILVA, F. G. S. ARAÚJO, M.P. TEIXEIRA, R. C. GOMES, F. L. VON KRÜGER. (2014). Study of the recovery and recycling of tailings from the concentration of iron ore for the production of ceramic, *Ceramics International*.

[5] SILVA, F. L., ARAÚJO, F.G.S., CASTRO, C.G., MENDES, J.J., KRÜGER, F.L. (2014). Recycling of Concentration Tailings of Iron Ore for the Production of Concrete Block (Pavers), *Materials Science Forum*.

[6] JONH, V.M., ZORDAN, S.E. (2001). Research & development methodology for recycling residues as building materials - a proposal. *Waste Management*, 21: 213-219.

[7] GOMES M. A. (2009). Caracterização Tecnológica no Aproveitamento do Rejeito de Minério de Ferro. Departamento de Engenharia de Minas, Universidade Federal de Ouro Preto, Ouro Preto, *Dissertação de Mestrado*, 77p.

[8] CUNHA J. C., BARBOSA J. S. F., MASCARENHAS J. F. (2012). Os greenstone belts. *In*: Barbosa J. S. F., Mascarenhas J. F., Corrêa-Gomes L. C., Domingues J. M. L. *Geologia da Bahia*, **2**: 203-326.

[9] CRUZ S. C. P., BARBOSA J. S. F., BARBOSA A. C., JESUS S. S. G. P., MEDEIROS E. L. M., FIGUEIREDO B. S., MENEZES-LEAL A. B., LOPES P., SOUZA J. S. (2014). Mapa Geológico da Folha Espinosa. Bahia, *PRONAGEO/UFBA-CPRM-FAPEX*.

[10] BORGES J. F., CRUZ S. C. P., BARBOSA J. S. F., SANTOS E. S. (2015). Structural framework of rocks of the Lagoa D'anta mine area, iron-manganese Urandi-Caetité-Licínio de Almeida District, Bahia. *Brazilian Journal of Geology*, **45**(2): 173-192.

[11] TESCAN, http://www.tescan.com/en. Acess 05/30/2015