IRON ORE PELLET CHARACTERIZATION THROUGH DIGITAL MICROSCOPY[1]

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Abstract

Vale evaluates the microstructure of iron ore pellets in order to understand their characteristics and behavior in the agglomeration process, and the correlation with conventional quality parameters. Efforts on image analysis development are in progress between Vale and PUC-Rio in order to improve both the qualitative and quantitative characterization. In the present work, digital microscopy techniques were developed allowing this kind of assessment. Employing a motorized and computer controlled optical microscope, low magnification mosaic images covering complete pellet samples were automatically obtained. The mosaics provide a powerful qualitative overview of the whole sample while allowing low resolution quantitative evaluation and measurement of the porosity mapping. Higher magnification mosaics were also obtained along pellet sample diameters. From these images, hematite, ferrite, slag and pores phase fractions were automatically measured, revealing the typical radial variation expected from pellets.

Key words: Pellet; Iron ore; Image analysis; Digital microscopy.

CARACTERIZAÇÃO DE PELOTAS DE MINÉRIO DE FERRO POR MICROSCOPIA DIGITAL

Resumo

A análise microestrutural das pelotas de minério de ferro é realizada na Vale com o intuito de estudar o processo de pelotização e também de avaliar sua qualidade. A Vale e a PUC-Rio estão envidando esforços para o desenvolvimento de rotinas de análise de imagens que melhorem a caracterização qualitativa e quantitativa das pelotas através de técnicas de Microscopia Digital. Com o emprego de um microscópio óptico motorizado e controlado por computador, foram automaticamente gerados mosaicos de imagens cobrindo cada pelota completamente. Estes mosaicos constituem-se em uma poderosa ferramenta de análise qualitativa da pelota como um todo e, além disso, permitem a análise quantitativa em baixa resolução e a medição do mapa de porosidade. Mosaicos em alta resolução também foram obtidos ao longo de diâmetros das pelotas. As frações de fase de hematita, ferrito, escória e poros foram automaticamente medidas a partir destas imagens, revelando a típica variação radial da microestrutura das pelotas.

Palavras-chave: Pelota; Minério de ferro; Análise de imagens; Microscopia digital

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1 INTRODUCTION

Iron ore pellets are widely employed in blast furnaces to produce pig iron. Because pellets are used in large proportion, which is still rising due to the lack of supply of high quality lump ores, there is an increasing interest to research and to improve the properties of iron ore pellets.(1)

The microstructural characterization of iron ore pellets contributes to the understanding of their properties and behavior in the agglomeration processes, and their use in blast furnaces. The mineralogical composition constitutes an important parameter that can be specified and controlled, as well the porosity and the spatial arrangement of pores.

Reflected Light Microscopy (RLM) is typically applied to characterize iron ores and their agglomerates because it is capable of distinguishing the most common mineral phases through their distinctive reflectivities.(2,3) In fact, RLM and digital image analysis are suitable tools for characterizing these materials.(2-6) They can provide fundamental information like mineralogy, porosity and texture.

Vale performs a qualitative evaluation of the microstructure of iron ore pellets, by visual examination under a reflected light microscope, regarding its correlation with conventional quality parameters. Nowadays, efforts on RLM and digital image analysis development are in progress between Vale and PUC-Rio in order to establish qualitative and quantitative characterization routines for iron ore agglomerates. Digital Microscopy techniques(7) were developed and employed to allow this kind of assessment.

Pellets present an inhomogeneous microstructure, mainly due to porosity, and radial variations are typical. Thus, traditional sample scanning must be done carefully to avoid producing average results that actually hide the spatial variations that are to be identified and measured.

In the present work digital microscopy was employed to acquire mosaic images(8) of pellet samples. These mosaics either scanned the sample along several diameters or covered the full sample surface in a single image. Image analysis was then employed to discriminate and measure the phase and porosity fractions and establish their systematic spatial variations.

Mosaic images are very useful both for qualitative and quantitative analysis as they provide a complete view of the sample, and the obtained measurements do not suffer from statistical limitations and edge problems associated with individual fields. On the other hand, at higher resolutions (and thence smaller field sizes) mosaic image files can quickly become so large that image processing becomes impractical. Thus it is important to combine both low resolution mosaics covering the whole sample and higher resolution mosaics covering sample diameters only, that reveal the radial distribution of phases.

2 MATERIALS AND METHODS

2.1 Sample Selection and Preparation

Pellet samples were mounted and prepared for observation by RLM. A conventional grinding and polishing procedure was employed. Pellets were cut at their equatorial plane leading to a polished section with ≈15 x 15 mm^2.

2.2 Digital Optical Microscopy

A Zeiss Axioplan 2 ie motorized and computer controlled microscope was used, with an AxioCam HR digital camera (1300 x 1030 pixels). AxioVision (V4.6, Carl Zeiss Vision) was used for microscope and camera control, and for image processing and analysis.

The following image acquisition conditions were employed:

a) Before image acquisition, a SiC reflectivity standard was used to generate background images for each objective lens, which were subsequently subtracted automatically from every acquired image.
b) Illumination was kept constant by direct digital control of the lamp voltage.
c) Camera sensitivity, exposure and white balance were optimized initially for a representative image of a given sample and kept constant there on.
d) Objective Lenses: 5X (NA 0.13); 20X (NA 0.40), leading to resolutions of 2.11 and 0.53 μm/pixel, respectively.
e) Mosaic images composed of several partially overlapping fields, completely covering the specimen surface, obtained with the lower resolution lens.
f) Mosaic images spanning the sample diameter, in different orientations, obtained with the higher resolution lens.

All images were acquired at 8 bit grayscale quantization. Color was not considered fundamental for the analysis, what allowed reducing image memory requirements by a factor of three.

2.3 Image Processing and Analysis

Each acquired image went through the following sequence of processing and analysis steps:

a) Delineation (edge enhancement) to reduce the well-known halo effect (9).
b) Segmentation by interactive thresholding of the pixel intensity histogram (10).
c) Measurement of the area fraction of each present phase.

The careful image acquisition conditions guarantee that the intensity of light reflected by each phase is reproducible and that the corresponding digital pixel value is stable. Thus, it was possible to use fixed intensity thresholds, effectively automating the segmentation step.

In the case of the lower resolution mosaic, that covered the whole sample, only porosity measurements were performed.

3 RESULTS AND DISCUSSION

Figure 1 shows a typical diameter scan of a typical pellet obtained with the higher resolution lens. The radial variation of phases, especially pores, is readily visible in the image. Employing the image analysis sequence outlined above, the phase fractions of hematite, ferrite, slag and pores were automatically measured. The results are shown in the plot of Figure 2. The expected radial variation for hematite and pores is clearly revealed.

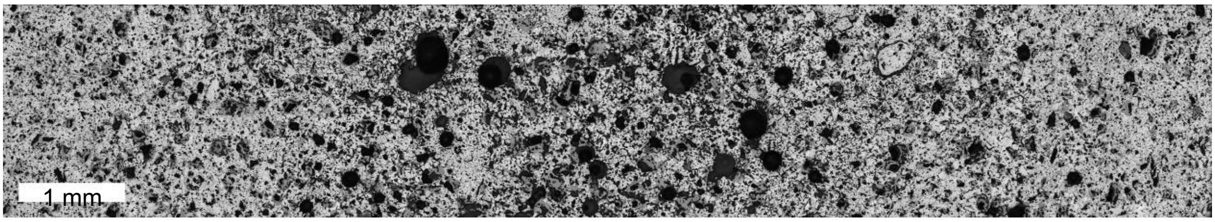

Figure 1 – High resolution mosaic image across the diameter of a pellet sample cross section.

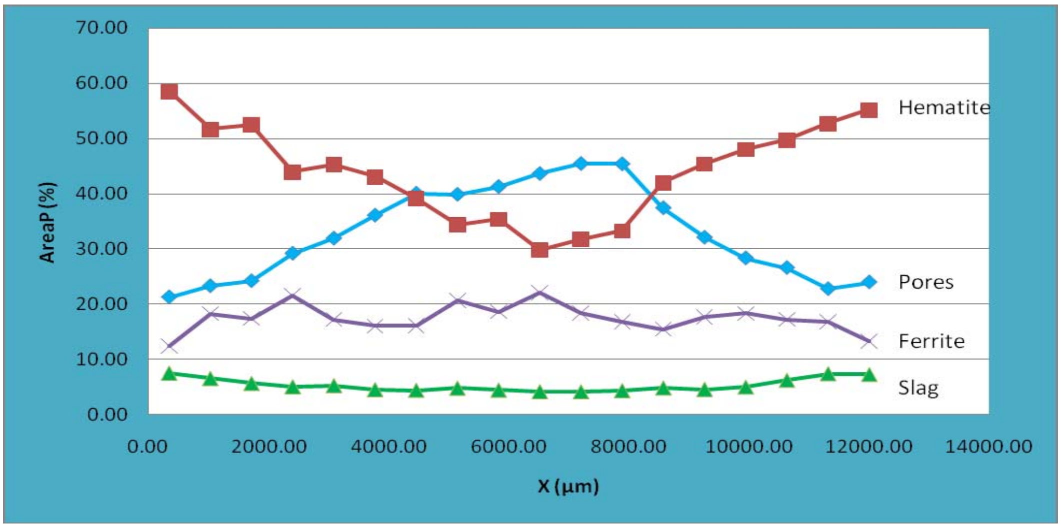

Figure 2 – Variation of phase fractions across the diameter shown in Figure 1.

Figure 3 shows a mosaic of the complete sample section obtained with the lower resolution lens. This image is very useful for qualitative analysis by a human operator. However, the accurate measurement of phase fractions is hindered by the limited resolution. Thus, in the present work, only results for porosity were obtained. The pseudo-color map in Figure 4 shows the spatial distribution of pores in the sample cross-section. Again, there is a useful qualitative aspect to this kind of map, aided, in this case, by the local measurements of pore area fraction, encoded by the colors shown in the side color bar.

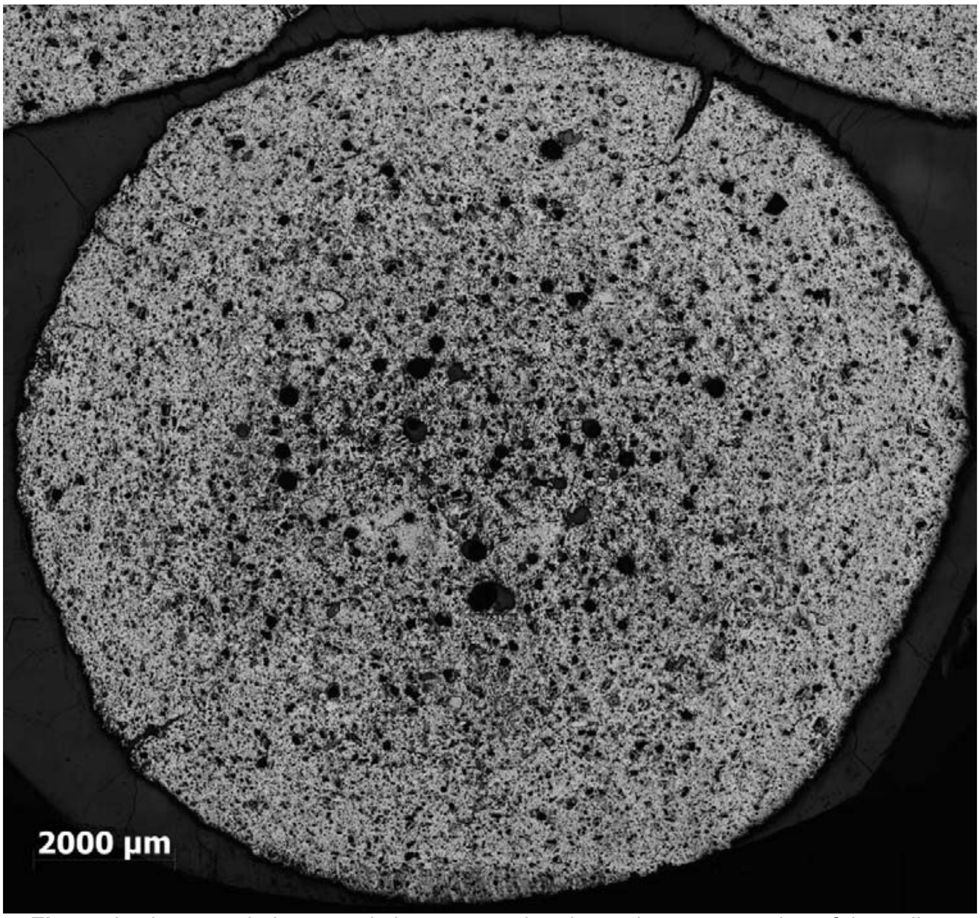

Figure 3 – Low resolution mosaic image covering the entire cross-section of the pellet.

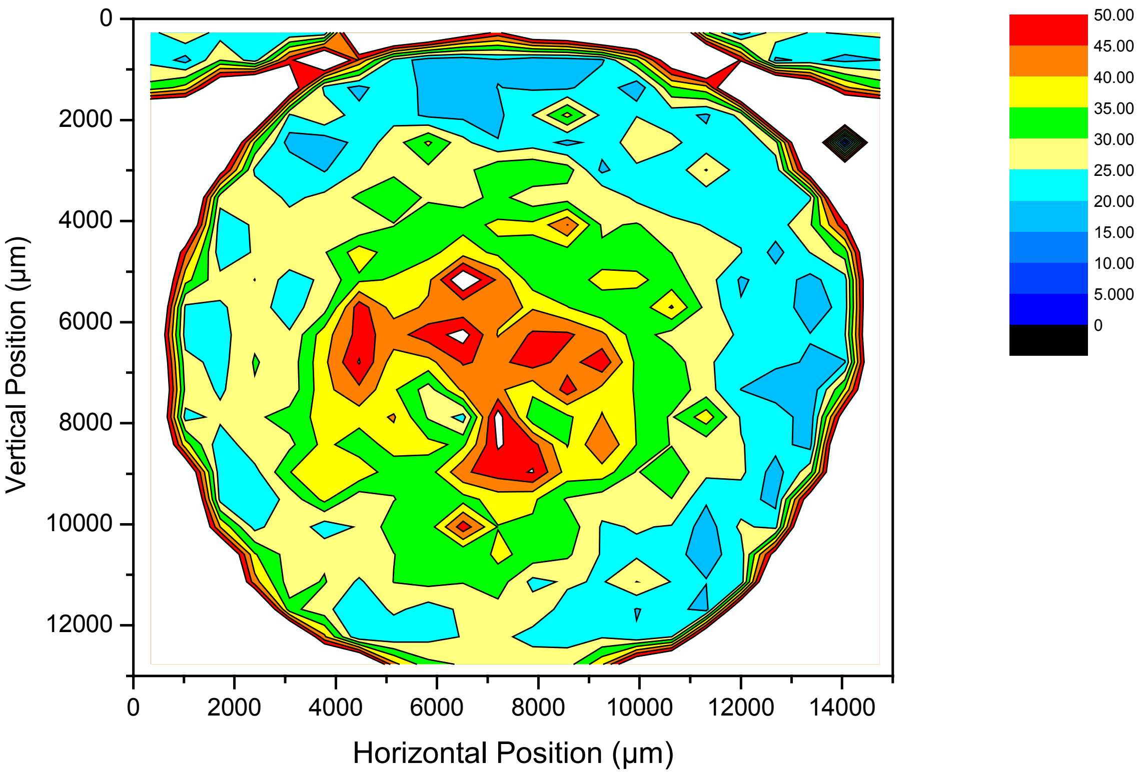

Figure 4 – Porosity map obtained from the mosaic of Figure 3. Values are shown as local area fraction (%).

4 CONCLUSION

A digital microscopy approach for the acquisition and processing of RLM images from iron ore pellets was developed.

These results are relevant because they provide a methodology for the evaluation of non-uniform materials such as iron ore pellets. It is possible, and practical, to acquire and process a low magnification mosaic image covering the whole sample surface and quickly obtain qualitative and quantitative information about the sample. When accurate measurements of finer phases is necessary, it is possible to produce diameter scans that use higher resolution images but create smaller, and readily treatable files.

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