Journal of Iron and Steel Research, International 24 (2017) 998-1006

Contents lists available at ScienceDirect

Journal of Iron and Steel Research, International

journal homepage: www.chinamet.cn

Three-dimensional structure and micro-mechanical properties of iron ore sinter

Wei Wang[1,2], Ming Deng[1,2], Run-sheng Xu[1,2,*], Wei-bo Xu[1,2], Ze-lin Ouyang[1,2], Xiao-bo Huang[1,2], Zheng-liang Xue[1,2]

[1] State Key Laboratory of Refractories and Metallurgy, Wuhan University of Science and Technology, Wuhan 430081, Hubei, China

[2] Key Laboratory for Ferrous Metallurgy and Resources Utilization of Ministry of Education, Wuhan University of Science and Technology, Wuhan 430081, Hubei, China

ARTICLE INFO

Key words:
Iron ore sinter
Mineral
Microstructure
Three-dimensional structure
Tumbler strength

ABSTRACT

A new analysis method based on serial sectioning and three-dimensional (3D) reconstruction was developed to characterize the mineral microstructure of iron ore sinter. Through the 3D reconstruction of two types of iron ore sinters, the morphology and distribution of minerals in three-dimensional space were analyzed, and the volume fraction of minerals in a 3D image was calculated based on their pixel points. In addition, the microhardness of minerals was measured with a Vickers hardness tester. Notably, different mineral compositions and distributions are obtained in these two sinters. The calcium ferrite in Sinter 1 is dendritic with many interconnected pores, and these grains are crisscrossed and interwoven; the calcium ferrite in Sinter 2 is strip shaped and interweaves with magnetite, silicate and columnar pores. The calculated mineral contents based on a two-dimensional region are clearly different among various layers. Quantitative analysis shows that Sinter 1 contains a greater amount of calcium ferrite and hematite, whereas Sinter 2 contains more magnetite and silicate. The microhardness of minerals from highest to lowest is hematite, calcium ferrite, magnetite and silicate. Thus, Sinter 1 has a greater tumbler strength than Sinter 2.

1. Introduction

Iron ore sinter, a lumpy material consisting of various minerals and pores, is one of the primary raw materials for iron production in a blast furnace[1]. The microstructure of minerals is known to influence the strength of iron ore sinter[2,3]. However, the sinter is opaque, and thus its three-dimensional (3D) structure characteristics cannot be obtained directly from outside observation. The traditional analysis method is to study the mineral composition and microstructure based on two-dimensional (2D) cross-section images of iron ore sinter that are obtained by microscopy[4,5]. Fan et al.[6] developed a system to calculate the mineral composition of sinter accurately and rapidly based on the features of mineralogy in micrographs of sinter. Lv et al.[7,8] investigated the relationship between mineragraphy features of iron ore sinter and its gray histogram, as well as the relationship between texture features and the mineralogy phases in iron ore sinter. However, a two-dimensional cross-section figure does not fully display its complicated 3D characters because the mineral structure in sinter is rather complicated. Thus, actual microstructure and mineral composition cannot be obtained directly and accurately through a 2D plane figure.

With the progress of computer science and technology, visualization technology based on 3D reconstruction has been developed[9]. A 3D image can be obtained using a 3D reconstruction technique. Shatokha et al.[10,11] estimated the iron ore sinter porosity using a 3D image based on the standard laboratory X-ray tomography method. Kasai et al.[12] quantified the 3D structure of voids in sinter cakes prepared from raw mix with a range of coke contents. Kasama et al.[13] developed a new analysis method employing X-ray computerized tomography for evaluating sinter pore structure based on a network model. Nakano et al.[14] investigated the 3D structure of iron ore sinter using an X-ray CT and a 3D image analysis system. The internal scan image of

* Corresponding author. Ph.D.; Tel.: +86 18810490945.
E-mail address: *xu_runsheng@163.com* (*R.S. Xu*).

Received 26 October 2016; Received in revised form 19 January 2017; Accepted 31 January 2017
Available online 15 October 2017
1006-706X/

the object can be obtained using the X-ray CT; however, its popularization and application are limited because of low image resolution and rather expensive equipment[15].

In view of the deficiencies of the above analysis methods, an approach to quantification of the mineral and microstructure of iron ore sinter is proposed in this paper based on serial sectioning and the 3D-restruction method[16-21]. Compared with 2D images, information about the microstructure is more comprehensive and intuitive through 3D image analysis. The 3D morphology of mineral structure can be observed from various angles through rotation in three-dimensional space. Furthermore, quantitative analysis of minerals can be achieved using a volume proportion calculation based on the statistics of the pixels of each mineral. This method not only has high resolution and low cost but also benefits the further study of the mineral composition and microstructure of iron ore sinter. Moreover, the microhardness of minerals was measured using a Vickers hardness tester. The relationship between tumbler strength and the 3D morphology of mineral structure, as well as the microhardness of minerals, was investigated in this study.

2. Experimental Materials and Method

2.1. *Iron ore sinter sample*

To compare and analyze the 3D morphology and distribution character of iron ore sinter, two different sinters with different basicities were selected from a China ironmaking plant. The chemical composition of iron ore sinters was detected by X-ray fluorescence (XRF) using a Shimadzu sequential X-ray fluorescence spectrometer. The tumbler strength was tested according to Chinese standard GB8209-87. The tested results of two iron ore sinters are listed in Table 1.

Table 1
Chemical composition and properties of iron ore sinter samples

Sample	Composition/mass%						Basicity	Tumbler strength/%
	TFe	FeO	SiO_2	Al_2O_3	CaO	MgO		
Sinter 1	55.42	7.06	4.75	1.82	9.97	2.39	2.10	80.11
Sinter 2	54.03	8.48	5.83	2.31	11.07	3.05	1.90	77.07

2.2. *3D-restruction method*

A 3D image of iron ore sinter was obtained based on the serial sectioning and 3D-restruction method. The details of each step are shown in Fig. 1[22,23]. First, the iron ore sinter was smoothed and fixed to glass plates. After grinding and polishing, two-dimensional microscopic images of samples were observed under an optical microscope at a magnification of 200. Four positions of each sinter were selected randomly for image acquisition. Each image was merged with 9 photos (three rows and three columns). Second, different minerals in photos were segmented, and marked with different colors. Third, the samples were polished again to obtain the microscopic image of the second layer. The spacing between two layers was approximately 5 μm and the total number of layers of iron ore sinter in this study was 40. Fourth, a three-dimensional reconstruction technique was used to realize the 3D visualization of

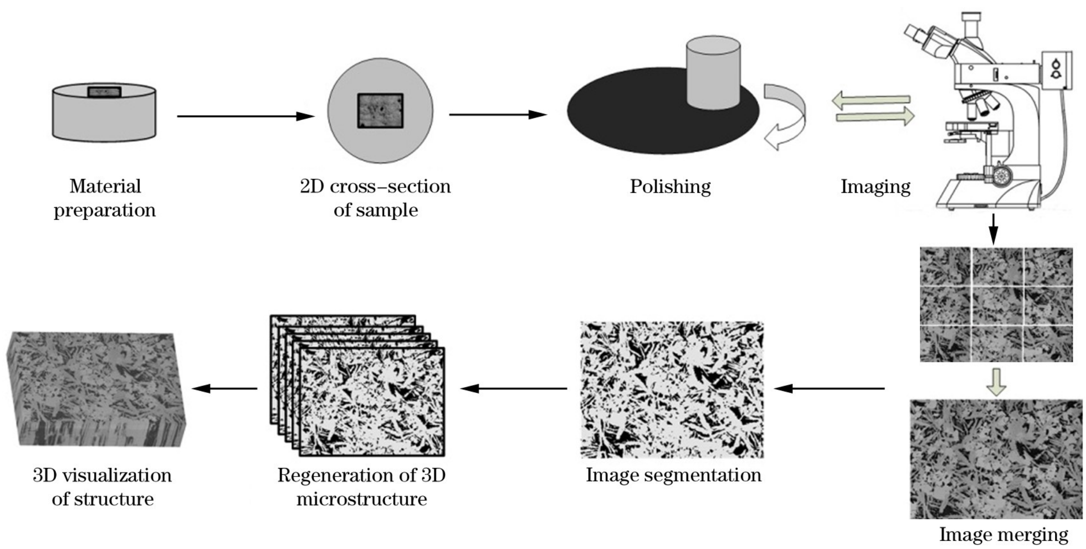

Fig. 1. Flow chart of serial sectioning and 3D reconstruction process.