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Research Paper

High resolution X-ray microtomography for the characterization of pore structure and effective thermal conductivity of iron ore sinter

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HIGHLIGHTS

- The pore properties of porous sinter cake were obtained and characterized by X-ray microtomography.
- The thermal behavior of sinter cake was investigated by simulation at pore level.
- From simulations based on real geometry, the effective thermal conductivity of sinter cake was reported.
- Micro CT-simulation approach predicts the effective thermal conductivity better than some simplified geometric models.

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ABSTRACT

Thoroughly understanding of the thermophysical properties of porous sinter is especially important for operation optimization and energy saving in integrated steel mills. Under this prospect, nondestructive X-ray microtomography was applied to characterize the pore structure and following simulations for estimating the sinter effective thermal conductivity were performed. Three sinter cakes produced from pilot-scale sinter pot tests under three granulation moisture levels were scanned with resolution ratio of 42 μm. The reconstructed sinter cakes have various complex pore distributions, leading to remarkable anisotropic thermal conductivities and complicated temperature field. The pores smaller than 300 μm dominate the number frequency in sinter cake, while a small amount of pores larger than 1 mm account for ~94% of the total pore volume, which determine the thermal behavior greatly. The estimated effective thermal conductivities of three samples are 0.847, 0.865, 0.558 W/m K, corresponding to the porosity of 48.1%, 49.1% and 59.4% respectively. Comparing these values with values of similar iron agglomerates in the literature, some empirical correlations and analytical models, the results proved that CT-simulation is a valid approach for capturing the peculiar details of the real sinter porous structure, thus to predict thermal behavior with higher accuracy than the simplified geometric models.

1. Introduction

In most integrated steel mills, the iron ore sintering is an important pre-process technology to provide sinter burden to blast furnaces for ironmaking. The iron ore sinter is a porous lumpy material formed by packed bed of granulated mixture undergoing a high temperature partial melting process. Due to the bonding effect of the solidified melt, the produced sinter has some complex structures composed of irregular solid constituents, interparticle voids and intraparticle pores [1,2]. Thoroughly understanding of the thermophysical properties of porous sinter is needed to achieve optimal performance of the related processes such as flame front propagation in sintering bed [3–5], waste heat recovery in sinter coolers [6–8] as well as gas-solid heat transfer in blast furnace [9,10].

For the precise characterization of the effective thermal conductivity of porous medium, the random orientation of the pore structure and solid constituents could not be neglected. Traditional methods recovering the geometric parameter to determine the sinter effective thermal conductivity can be categorized into experimental measurement and some empirical correlations or analytical models based on simplified geometries. In term of the experimental measurement, Akiyama et al. [11] measured the thermal conductivities of pure iron oxides and reduced sinter by applying laser flash method. Sundarmutri et al. [12,13] determined the thermal conductivity of iron ore pellets by recording temperatures at centre and surface of the fired pellet and solving the radial heat balance problem. Tian et al. [14] investigated the feasibility of using transient plane source method to measure the effective thermal

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conductivity of sinter. In the modeling way, Nishioka et al. [15] conducted 2-dimensional heat transfer simulation to estimate the effective thermal diffusivity of porous sinter based on the microstructure image with the actual sample size of 300 μm ∗ 273 μm. A new meso-porous unit-cell model was attempted by Aizawa et al. [16] for predicting sinter thermal conductivity by combining the phase field method with the finite element method. Other analytical models such as traditional unit cell model [11] and fractal model [14] were also proposed and acceptable agreements between their predicted values and experimental results could be got. To sum up, though there have been a variety of methods to measure and predict the effective thermal conductivity of iron agglomerates, it is widely acknowledged that the pore properties including size, shape and distribution have significant influence on the thermal properties and the related heat transfer performances.

Recently the numerical modeling approaches and the X-ray tomography technology have been advanced therefore the simulations can now be performed on 3-D realistic geometries with fast computational speed and high resolution ratio [17]. There have been quite a large amount of research work combining 3-D geometry reconstruction and numerical simulations for the effective thermal conductivity estimation of varies porous medium including metal foams [18,19], hydrate-bearing sediments [20] and insulating concrete [21], etc. However, to the author's knowledge, there are still no report on the iron ore sinter with this methodology. Though the CT method was first introduced to the research field of iron ore sintering by Japanese researchers in 1990s, most of the previous work was only focused on the evaluation of pore network and its influence on the sinter bed permeability [22–25] and sinter metallurgy quality [26].

In present work, based on the high resolution X-ray tomography results, the pore properties of sinter cake samples got from sinter pot tests under three moisture levels were evaluated quantitatively. The effective thermal conductivity of these samples were estimated by finite element method with real 3-D geometry and compared with the previous experimental results and predicted results by some simple models. Finally, the relationship between pore properties and the effective thermal conductivity was discussed and elucidated.

Table 1
Ore blend composition, sintering conditions and the tested cases.

Ore blend composition (wt%)			
Ore 1 (Australia)	33.33		
Ore 2 (Australia)	16.67		
Ore 3 (Australia)	16.67		
Ore 4 (Brazil)	16.67		
Ore 5 (Brazil)	16.67		
Sintering conditions			
Return fine (wt% total mix basis)	20.0		
Coke rate (wt% total mix basis)	4.05		
Basicity (CaO/SiO_2)	1.9		
Granulation time (min)	10		
Bed height (mm)	600		
Ignition suction (kPa)	6		
Ignition temperature (°C)	~1100		
Ignition time (s)	90		
Sintering suction (kPa)	16		
Tested case conditions			
Case number	1	2	3
Aim moisture (%)	6.5	7.0	7.5
Experimental moisture (%)	6.26	6.72	7.30

2. Methodology

2.1. X-ray computed microtomography

The scanned sinter cakes were produced in a pilot-scale sinter pot with diameter of 300 mm and bed height of 600 mm. The sintering tests were conducted according to the standard operation procedures which are described specifically in previous work [27,28] and the related testing conditions are given in Table 1. Three ~30 ∗ 30 ∗ 30 mm^3 samples for XCT measurement were excavated from the middle position of three sintered cylinders with varying the granulation moisture of 6.5%, 7.0% and 7.5%.

Fig. 1 illustrated the MicroXCT-400 instrumentation applied for the micro X-ray computed tomography. The parameters set up for the sample scanning are listed in Table 2 [28]. Due to the trade off between dimension of the sample being scanned and the resolution ratio associated with large computational cost, the resolution ratio used in present study was determined at 42 μm, which is believed to capture most of the microstructural details for evaluation of the sinter porous structure and the following estimation of effective thermal conductivity.

Table 2
Set up of the MicroXCT-400 scanning conditions.

Item	Value
Voltage (kV)	139
Current (μA)	49
Exposure time (s)	5
Source-to-sample distance (mm)	100
Detector-to-sample distance (mm)	60
Pixel size (μm)	42

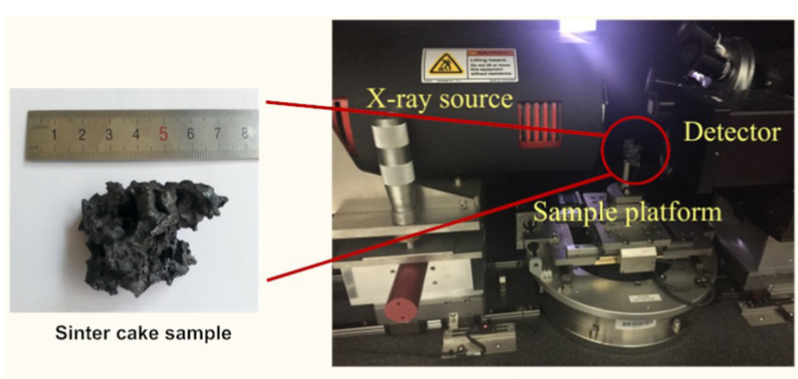

Fig. 1. MicroXCT-400 X-ray computed tomography system.