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# Process Analysis for Blast Furnaces by the Discrete Element Method†

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***Abstract:***

*Discrete element method (DEM) calculation revealed the following: A packed bed in a blast furnace is supported by the formation of a network structure by particles receiving heavy stress. And the stress at the contact point of coke in the network can exceed the compressive strength. Shaft angle strongly affects solid flow and strength of stress in a blast furnace. On the assumption that the particle size of coke in molten pig iron decreases due to carbon dissolution, a coke powder layer is formed in the stagnant zone. The layer can protect the refractory of hearth against erosion, and its thickness is strongly affected by the depth of hearth and load of burden.*

## 1. Introduction

With the increasing demand for reduced $CO_2$ gas emission in recent years, improvements in productivity and energy efficiency in steel works have become a social responsibility. Extremely strict requirements for $CO_2$ gas reduction are now placed on ironmaking, a process in which iron ore is reduced and melted by consuming large amounts of coal, and in which energy is suppl ` V Mp ombestib ı ɔ yproduc ℵ V ases AV t ñ ɔ rocesses+ - n the steel

place by charging sinter (in the form of agglomerated iron) ore and coke (in the form of agglomerated coal) from the top of the furnace, while blowing hot blast into the furnace bottom. High energy efficiency and productivity are achieved in the process by a countercurrent moving bed reaction. There now is an orientation toward reduced agent rate (RAR) operation and increased hot

Studies using continuum models, discrete models, or combinations of the two seem to be necessary to succeed in elucidating the formation mechanisms behind the limiting phenomena and quantitatively grasping ways to minimize the limitations. Discrete models, however, have only been recently applied to blast furnaces (compared to continuum models), and the calculations by discrete models do not apply the ] ed totot p ]

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tive powder simulation methods covering multi phase

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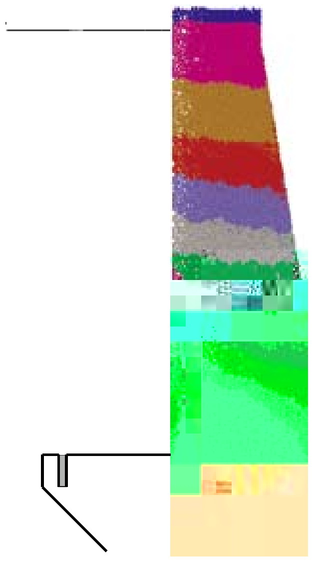
fows[1]. Cognizant that the raw materials used in iron-making are granular bodies, Tanaka et al. applied DEM to calculations on gravitational discharge from the hopper, blast furnace deadman formation, furnace-top burden segregation, the behavior of materials in the raceway, etc. in steel industry studies of the 1980s



of fuids (gas and liquid fows) were ignored in both simulations. In the hearth model, we assumed that coke is consumed in the peripheral area directly below the tuyeres via direct reduction by the FeO in the slag and carbon dissolution[16,17], thereby resulting in a gradual decrease in the particle size of the coke in the molten pig due to carbon dissolution. The load distribution on the hearth was reproduced by causing particles to be piled in the manner shown in **Fig. 2**.

Verifcation is indispensable in numerical simulations, including DEM. Simulation results obtained when particles are discharged from the raceway position are shown in **Fig. 3**, (a) and (b), as compared with the results of a scale-model burden descent experiment[18]. The calculated deadman volume (stagnant zone) and timeline profle show the same tendencies observed in the model experiment. Results of a simulation of the effect of hearth coke consumption on the renewal of the stagnant zone are presented in **Fig. 4**, (a) to (d). As shown here, the stagnant zone cannot be renewed without hearth coke consumption (Fig. 4, (a)). According to the calculated results, the intervals between the timelines in the hearth are narrow in the peripheral zone and center zone, and wide in the intermediate area (Fig. 4, (b) to (d)). **Figure 5**, (a) to (c) shows results of a dissection analysis of No. 4 BF, West Japan Works (Kurashiki), and calculated solid flows in the hearth. The features of the timelines by DEM simulation are similar to the crystallite size distribution (distribution of hearth coke graphitization (Fig. 5, (a)) in the dissected furnace. On the assumption that the particle size of coke in molten pig decreases due to carbon dissolution, as shown in Table 1, these results confirm that a coke powder zone like that observed in the dissected furnace is formed in the stagnant zone (Figs. 5, (b) and 5(c)).

## 3. Results and Discussion

The design of the blast furnace body is very important for the stability of the burden descent, a factor which itself is important for the stability of blast furnace operation and the furnace body life. An important factor in stable burden descent is the furnace profile, par-