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Review article

The evolution of structural order, microstructure and mineral matter of metallurgical coke in a blast furnace: A review

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ABSTRACT

The implementation of pulverized coal injection technology has resulted in the reduction in the amounts of coke being used in the blast furnace, which has led to increased demands for high quality cokes to provide enhanced performance. Under the twin pressures of resource shortage of coking coals and continuous requirements for improved coke quality, an in-depth understanding of coke behavior in blast furnace has become very important and pertinent. This review article is focused on a comprehensive investigation on the evolution of structural order, microstructure and mineral matter of metallurgical coke in a blast furnace and presents various mechanisms of coke degradation during its descent in a blast furnace toward establishing reference standards for coke quality and performance. Coke structure, microstructure and reactivity were investigated as a function of temperature, its location in the blast furnace and under the influence of alkalis above the tuyere level. The transformation of coke in the blast furnace hearth and its dissolution into hot metal were also reviewed. The current indices for evaluating coke quality were examined based on the modifications of coke structure, and several unresolved issues in the field requiring further research were identified. This literature survey has shown that while crystalline order and microstructure had a strong influence on carburization, gasification reactions and the strength of coke, factors such as mineral matter, alkalis, temperature were among some of the important factors that affected the degradation of coke in a blast furnace.

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1. Introduction

The blast furnace (BF) is continuing to evolve under the twin pressures of cost escalation and reductions in greenhouse gas emissions. Aging facilities, stringent environmental regulations, large capital costs and limited supply of coking coals have all resulted in the need to find further efficiencies and to minimize coke consumption in particular [1,2]. While the usage rates for metallurgical coke have been reduced to levels unheard of fifty years ago, there still is room for further improvements. Coke fulfills four major roles in the blast furnace [3]: (i) as a source of reducing gas for the reduction of iron ore and for the regeneration of CO from CO_2; (ii) a source of energy/heat; (iii) supporting the weight of the burden and providing a matrix of permeable material especially in the lower regions of the furnace; and (iiii) a source of carbon for carburizing hot metal. The significant role played by coke in the blast furnace operations has been confirmed rigorously through various industrial tests. While low temperature and high-oxygen furnaces are being investigated as the next generation of iron making, iron making is currently dominated by the blast furnace. With increasing demands for higher coke quality, one of the key requirements is to design cokes with an appropriate reactivity, strength and other properties for both current/emerging technologies. To do so effectively, the evolution of coke characteristics in the blast furnace and the co-relation between the coke reactivity and other fundamental properties needs to be fully understood.

Coke reactivity is known to affect carbon consumption in a blast furnace through a shift in the transition of FeO–Fe reduction equilibrium point [4,5]. Under conditions that maintain appropriate coke strength, higher the coke reactivity, lower is the thermal reserve zone temperature due to the endothermic reaction of intensified coke gasification. Thus, CO gas utilization moves to a higher end shifting the equilibrium point of FeO–Fe reduction from W to W′ (Fig. 1) and reducing associated energy consumption [6–8]. The characteristics of coke dissolution into hot metal were also found to influence the descending rates for coke [9] and the final level of carburization of liquid metal [10,11].

A number of dissection studies have been carried out on blast furnaces worldwide. In 1950s there were a number of BF dissections in the former Soviet Union [12] and in the United States [13]. In the 1970s, over ten blast furnaces were dissected successfully in Japan [14,15], and a 23 m^3 experimental BF at Shougang [16] and a 0.8 m^3 experimental BF at Pangang [17] were dissected in China. Japanese dissection studies on Nagoya 1 BF of Nippon Steel showed that there was no appreciable change in mean coke size and its Drum Index (DI) from room temperature to 1000 °C, corresponding to upper shaft to middle shaft region. The degradation of coke was marginal. In the region corresponding to middle shaft to the bottom of the cohesive zone (1000–1400 °C), there are surface degradation of coke, not much change in the mean size, a lowering of DI with increasing temperatures and not much generation of fines. In the lower regions corresponding to lower shaft to just above the tuyere level (1400–1600 °C), mean size of coke decreased rapidly with increasing temperature; fines were generated due to significant abrasion and impact forces [18]. Other studies from Kawasaki Steel and Sumitomo Metals showed a similar behavior indicating a ∼25% reduction in coke mean size below tuyere level along with ∼8.5% reduction in coke strength. Fine generation increased rapidly ∼1–3 m above the tuyere level and these were preferentially distributed along the BF periphery.

Recently, a dissection was carried out at Laiwu Steel in China in December 2007 on a 124.87 m^3 blast furnace of 3.2 m hearth diameter with 8 tuyeres. Before shutdown, the charged materials used were typical for a large BF and the injection of pulverized coal was 80 kg/thm with 539 kg/thm coke ratio and regular blast furnace performance. The percentage of +60 mm, 40–60 mm, 25–40 mm, 10–25 mm and −10 mm size particles in the coke charge was determined as 15.6%, 33.2%, 30.3%, 6.4% and 4.5% respectively [19]. The behavior of the lumpy zone, the cohesive zone and the dripping zone in blast furnace were studied in detail by the methods of layered removal, stratified sampling and point-by-point sampling. A schematic of the burden distribution in the blast furnace is shown in Fig. 2 with specific focus on the distribution of burden layers, and parameters for the softening/melting zone, drippy zone and the raceway [19–21]. The stock column skeleton provided by the coke can be seen clearly as gray/black dots. The inner state of the dissected blast furnace was found to be quite similar to the results obtained in previous dissection research [12–17].

Iron-bearing materials were found to bond closely in the cohesive zone. The morphology of pellets and sinter could be easily identified outside the cohesive zone, while that of iron-bearing materials could not be identified inside the cohesive zone. The cohesive zone showed a stratification and ring structure with both

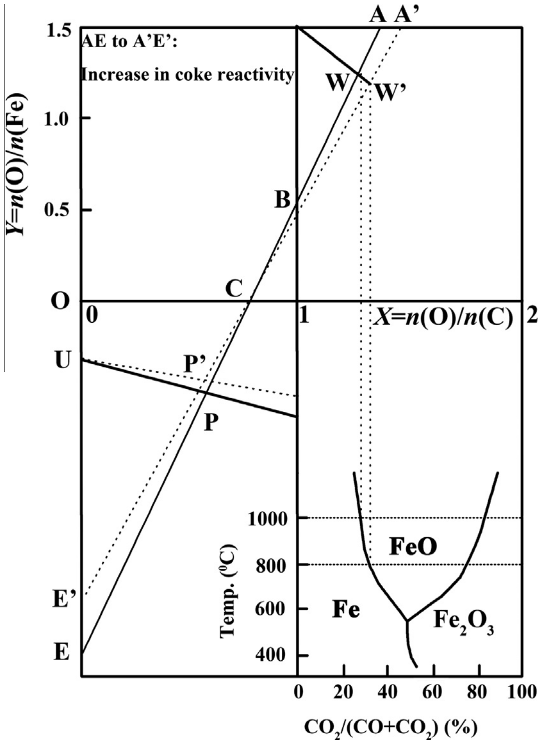

Fig. 1. RIST operating diagram combined with Baur–Glaessner equilibrium diagram.