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Influence of temperature and time on reduction behavior in iron ore–coal composite pellets

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ABSTRACT

In this study, the kinetics of reduction in iron ore–coal composite pellets has been investigated. Kinetic parameters were estimated from thermogravimetric data. X-ray diffraction was used to identify the products obtained after heating the composite pellet to different temperatures. Experimental results indicate that the reduction process is diffusion controlled below 900 °C. There is a change in reduction mechanism above this temperature and mixed control is observed up to 1100 °C above which reduction is phase-boundary controlled. The reduction rate has also been observed to decrease with progress in reduction.

1. Introduction

Direct reduction refers to using gas or solid reductant in the reaction of iron ore reducing into metallic iron under softening temperature. The products are called direct reduced iron (DRI). The coal-based direct reduction process makes ferric oxide metallic Fe into metallic iron under solid state. When the reaction temperature is low, reduction rate will be slow. When the reaction temperature is too high, it is prone to bond and will cause the waste of energy. An appropriate temperature can increase the productivity of the reduction process.

The coal-based direct reduction has been widely studied in the past two decades [1–8]. The main work has focused on the process conditions test, energy saving and reducing consumption. The reduction kinetics has been studied little. Many investigators [9–16] tried to establish a generalized kinetic equation for the reduction of iron oxides. Chowdhury and Roy [9] applied genetic algorithm (GA) to estimate the rate parameters from the experimental data during solid state reduction of iron ore in the presence of graphite. The results show that, the reduction of iron ore has been considered in three elementary steps, namely hematite to magnetite, magnetite to wustite and wustite to iron. Thermal analysis data identified the individual thermal reaction regions associated with developments of individual iron phases during the heating and were used to calculate the corresponding kinetics of the reduction process by Zhuang et al. [10]. Reduction kinetics of iron ore fines were investigated under fluid bed conditions with hydrogen-rich gas mixtures in the temperature range from 400 °C to 700 °C at a pressure of 10 bar by Weiss et al. [11]. The kinetic parameters were estimated without considering a specific surface area. Strezov [12] investigated the fundamental mechanisms of iron ore reduction with biomass wood. The reduction reactions were divided into three major temperature events with the first being exothermic while the two higher temperature regions exhibited endothermic heat effects. A mathematical time-dependent and isothermal model based on the grain model has been developed to simulate the kinetic and thermal behaviors of a porous iron oxide pellet undergoing chemical reactions with a mixture of hydrogen, carbon monoxide, carbon dioxide and water vapor by Valipour et al. [13]. A mathematical model of the coal-based direct reduction process of iron ore in a pellet composed of coal and iron ore mixture was investigated using the finite-control volume method by Shi et al. [14]. A comprehensive model approach and experimental results were used to test possible rate-determining steps for direct reduction in pellets containing fine magnetite and coal by Coetsee et al. [15]. Heat transfer was found not to be limiting for the reduction reaction. An attempt has been made to study the effect of coal quality on the reduction kinetics of iron ore–coal composite pellets under non-isothermal condition in inert atmosphere by Sah and Dutta [16]. However, the comparison of the models is still relatively rare. As the development of new reduction technology, the study of reduction mechanism is becoming more and more urgent. The reaction mechanism is usually based on the analysis of experimental data through the reaction kinetics models. In this study, the reduction characteristics of composite pellets are to be investigated. Model equations will be fitted to these data, and the apparent activation energy will be calculated.

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2. Materials and experiments

2.1. Materials

The sample ore used in this study was obtained from Miyun Beijing. The chemical composition of the sample was $Fe_{total} = 68\%$, $FeO = 27.4\%$, $SiO_2 = 4.44\%$, $CaO = 0.18\%$, $Al_2O_3 = 0.56\%$, $MgO = 0.48\%$, and $S = 0.05\%$. The bituminous coal used in this study was obtained from Datong. The main constituents were fixed carbon = 74.48%, volatile matter = 12.51%, and ash = 13.01%. The particle size ranged from 74 to 147 μm, and the average size was 109 μm. The coal was devolatilized at 600 °C for 1 h in nitrogen before mixed. Then we treated the material for longer times and at higher temperatures. When treated for 3 h at 900 °C, there was no any further weight loss. This indicated that most of the volatile matter was removed.

2.2. Experimental

The average particle size of iron ore concentrate was 74 μm. A mixture of fixed carbon C_{Fix} and oxygen O_{TFe} in iron ore particles at a mole ratio of 1:1 was used throughout the study. 1% bentonite was used as binder and mixed for 10 min in a mixing machine. Pellets with a particle

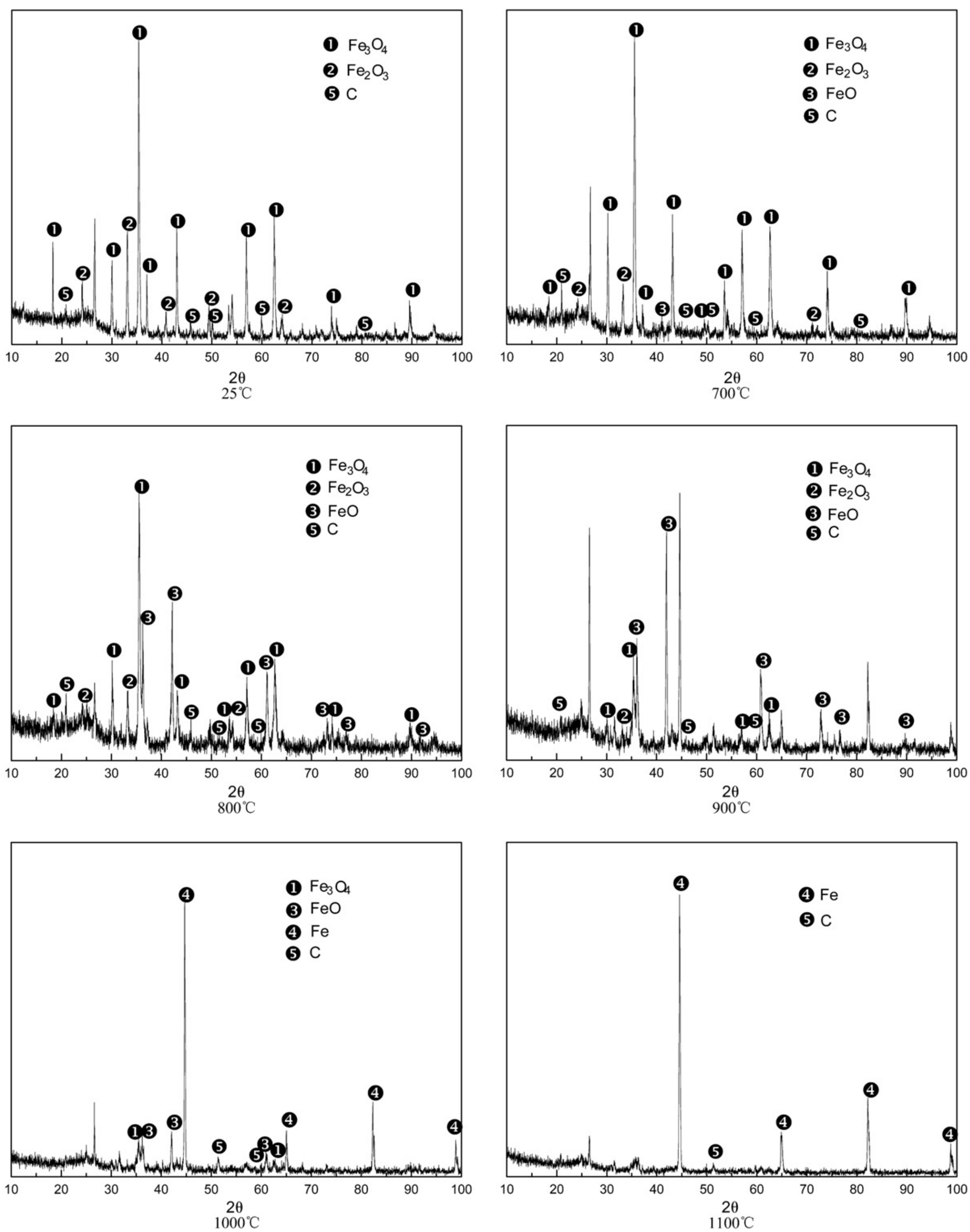

Fig. 1. XRD analysis of samples at different temperatures.