Investigation of composition and properties of EAF dust for metal reduction

D A Kalganov¹,², D A Pavlov¹, A P Anzulevich¹, L N Butko¹, V A Tolkachev¹ and Z Peng³

¹ Chelyabinsk State University, 129 Br. Kashirinykh Str., Chelyabinsk, 454021, Russia
² ITMO University, 49 Kronverkskiy pr., St. Petersburg, 197101, Russia
³ Central South University, Changsha, Hunan, 410083, China

E-mail: dezwark@gmail.com

Abstract. In this work, we investigated the composition and structure of the dust of electric arc steelmaking furnaces. We considered the process of direct reduction of metals (mainly Zn and Fe) with biochar from EAF dust. For better control over chemical transformations, it is proposed to use microwave heating of a mixture of EAF dust and biochar. Possible chemical and phase transformations for complex oxides in the composition of EAF dust have been determined.

1. Introduction

The tasks of recycling of waste from the metallurgical and pulp and paper industries are acutely faced by the world industrial community.

The possibility of using such raw materials as secondary raw materials for obtaining useful materials is an important applied problem of related scientific research [1]. Good opportunities for these technologies are provided by the development of new metallurgical technologies using microwave energy [2].

During the production and processing of various types of steel in Russia, up to 2000 tons of electric arc furnace (EAF) dust are generated daily. Dust and gas cleaning systems effectively capture about 99% of this secondary raw material, but its further processing is complicated by both the relatively low content of useful metals and the presence of thermally highly stable phases [3,4]. The need to reduce dust formation and develop a technology for utilization of dust captured by filters is due to its negative impact on the environment and human health.

Also, in recent years, technologies of iron reduction from iron-containing compounds using pyrolyzed carbon-containing biomass - biochar - have attracted much attention [2,5]. The main advantages of their use are a decrease in the reaction temperature, a decrease in slag formation and the absence of harmful substances in the reducing agent. The use of microwave energy makes it possible to carry out all stages of this process, including endothermic ones, and to flexibly regulate the course of the process by changing the power of microwave radiation [6].

2. Methods and materials

X-ray phase analysis (XRD) of the samples was performed using a Bruker Advance D8 diffractometer (CuKα radiation, standard powder technique).
For the process of metal reduction from oxides, biochar was added to the initial samples of EAF dust in a ratio of 4:1.

To determine possible chemical and phase transformations, we used a NETZSCH Jupiter F5 differential scanning calorimetry (DSC) complex heated to 1473K in an argon atmosphere at a constant rate of 10º/min.

The sizes of EHP dust microparticles and the phase composition uniformity were determined from scanning electron microscopy images obtained using a Jeol JSM 6510la with preliminary deposition of a thin conductive Pt layer on the samples.

3. Results
According to the data of electron microscopy (figure 1), it can be concluded that the sizes of dust particles are in the range of up to 500 nm. The samples under study represent a statistically homogeneous mixture of phases:

![Figure 1. Microimages of EAF dust.](image1)

The composition of the samples was determined using the PDF2 database file (figure 2).

![Figure 2. X-ray diffraction plot of EAF dust samples.](image2)

Based on the XRD data, the following phase and elemental composition of the EAF dust sample was obtained:
Table 1. Phase and elemental composition of EAF dust.

| №  | Phase composition       | Content, % vol. | Equivalent elemental composition | Chemical element | Content, % vol. |
|----|-------------------------|-----------------|---------------------------------|------------------|-----------------|
| 1  | Fe+2Fe₂+3O₄             | 3.8             | O                               |                  | 37.6            |
| 2  | Mg₁.₃₅Fe₁.₆O₄           | 36.2            | Mg                              |                  | 9.7             |
| 3  | ZnO                     | 10.0            | Si                              |                  | 15.1            |
| 4  | CaMgSiO₄                | 15.0            | Ca                              |                  | 7.0             |
| 5  | Ca₈₄Mg₃(SiO₄)₈          | 7.6             | Fe                              |                  | 22.6            |
| 6  | SiO₂                    | 23.7            | Zn                              |                  | 8.0             |
| 7  | (Fe₀.₉₁₄Si₀.₀₈₆)(Fe₀.₉₉₈Si₀.₀₀₂)₂O₄ | 3.8             |                                  |                  |                  |

Common analysis and approximation of DSC and DTG curves by Gaussian curves showed the presence of 7 stages of thermolysis (figure 3):

![Figure 3. DSC samples of the mixture: EAF dust - biochar in a stoichiometric ratio of 4:1.](image)

The main chemical processes occurring during the direct reduction of iron with solid carbon C depend on the initial composition of the EAF dust, but generally correspond to redox reactions:

\[ \text{6Fe}_2\text{O}_3 + C \xrightarrow{750-1090 K} \text{4Fe}_3\text{O}_4 + CO_2 \]  \hspace{2cm} (1)

\[ \text{Fe}_3\text{O}_4 + C \xrightarrow{1090-1270 K} \text{3FeO} + CO \]  \hspace{2cm} (2)

\[ \text{FeO} + C \xrightarrow{1270-1455 K} \text{Fe} + CO \]  \hspace{2cm} (3)

\[ \text{ZnFe}_2\text{O}_4 + 3CO \xrightarrow{1170 K} \text{ZnO} + 2\text{Fe} + 3CO_2 \]  \hspace{2cm} (4)

\[ \text{ZnO} + C \xrightarrow{1210 K} \text{Zn} + CO \]  \hspace{2cm} (5)
4. Conclusion
As a result of the comparison shown in figure 3 of the stages of thermolysis with possible chemical transformations (1) - (5), we can say that the peaks at temperatures of 863K and 870K are most likely due to reaction (1) and the concomitant reaction with carbon monoxide, the peaks 1010K and 1020K correspond to reaction (2) in a similar way, and the peak at 1176 K corresponds to the Gibbs energy for reaction (5).

The recovery of EAF dust with the addition of biochar in the stoichiometric ratio was carried out in a multimode microwave resonator [4]. The resulting mixture consisted of a ferromagnetic fine powder of iron and silicates.

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