Effects of Different Carbon Content on the Extraction of Silicon Aluminum Alloy By Carbon Reduction Fly Ash

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Abstract. Effects of different carbon distribution on the extraction of silicon aluminium alloy by carbon reduction fly ash were studied. X-ray diffraction instrument was used to characterize phases of the products. The results showed that when the carbon content was 0.8 to 1.0 times that of carbon, alumina and silicon carbide were included in the reduction products. When the carbon content was 1.1 times that of carbon, the reduction products were Al, Al$_4$FeSi, Si, SiC and FeSi$_2$. When the carbon content was 1.2 times that of carbon, the reduction products were SiC, Si, Al and Al$_4$FeSi. With the increase of the amount of carbon, the effect of preparing silicon aluminium by carbon reduction fly ash was better. In this experiment, when the carbon content was 1.2 times that of carbon, the carbon reduction fly ash had the best preparation effect on silicon aluminium alloy.

1. Introduction
Fly ash is the fine ash collected from flue gas after coal combustion and it is the main solid waste discharged from coal-fired power plants$^{1-2}$. Fly ash is usually piled in the open air, which not only occupies a large amount of land, but also affects water, air, soil and human health$^{3-4}$. Therefore, improving the value-added utilization of fly ash has important economic value. The main components of fly ash are alumina and silicon oxide$^5$. Extracting silicon-aluminium alloy from fly ash can not only solve the problem of fly ash pollution, but also obtain new source of silicon aluminium alloy. This paper mainly studies the effect of different carbon content on the extraction of silicon aluminium alloy from carbon reduction fly ash.

2. Test materials and methods
The fly ash of a power plant in Liupanshui was selected as raw material. Main components of selected fly ash raw materials were silicon oxide, alumina, iron oxide, calcium oxide, titanium oxide, potassium oxide, magnesium oxide and others. The main components of fly ash were 45.3%, 23.6%, 11%, 4.2%, 3.2%, 1.5%, 1.3%, 10%, respectively. With charcoal containing 85% fixed carbon as reductant, calcium lignosulfonate as binder and appropriate amount of water mixed with fly ash in a certain proportion evenly. Under the single arm hydraulic press, 10 Mpa pressure was selected to press the prepared material into a mass of 24 mm in diameter and 20 mm in height. Considering the reaction of carbon with alumina, silica, ferric oxide, titanium oxide, calcium oxide and magnesium oxide in fly ash, the theoretical ratio of carbon to fly ash was calculated to be about 8:25. The carbon allocation amount selected in this experiment was 0.8, 0.9, 1.0, 1.1 and 1.2 times of the theoretical carbon allocation. The quality of calcium lignosulfonate is 8% of the total quality of charcoal and fly ash. The 25AB high frequency induction smelting furnace was used in the smelting equipment, and TD-2500 X-ray diffraction instrument was used to characterize the effect of
different carbon content on the extraction of silicon and aluminium from carbon reduction fly ash.

3. Results and discussion

3.1. Phase analysis of carbon reduction fly ash products XRD with carbon content of 0.8 times carbon

Figure 1 was an XRD pattern of the experimental products of extracting silicon and aluminium from fly ash with 0.8 times carbon content. Figure 1 showed that under the reaction conditions of 0.8 times carbon content, 2273K reduction temperature and 30 minutes heat preservation, no Si and Al were formed in the reduction products, but Fe$_2$SiO$_4$ and SiC were formed, Al$_2$O$_3$ and SiO$_2$ were also formed. This showed that the content of reducing agent charcoal was insufficient, and Al$_2$O$_3$ and SiO$_2$ in fly ash could not be reduced to Al and Si completely. The formation of SiC indicated that impurities were generated and carbon was consumed in the experimental reaction.

It was possible that there were the following reactions in the carbon reduction fly ash under the atmosphere:

\[
\begin{align*}
\text{SiO}_2+3\text{C} &= \text{SiC}+2\text{CO(g)} \\
\text{Fe}_2\text{O}_3+\text{SiO}_2+\text{C} &= \text{Fe}_2\text{SiO}_4+\text{CO(g)}
\end{align*}
\]

Figure 1 XRD pattern of fly ash products reduced by carbon with carbon content of 0.8

3.2. Phase analysis of carbon reduction fly ash products XRD with carbon content of 0.9 times carbon

Figure 2 was an XRD diagram of the experimental products of extracting silicon and aluminium from fly ash with 0.9 times carbon content. Figure 2 showed that under the reaction conditions of 0.9 times carbon content, 2273K reduction temperature and 30 minutes heat preservation, Al, Si and a small amount of SiC were present in the reduction products, as well as the formation of Fe$_2$SiO$_4$ and FeSi alloys and the presence of Al$_2$O$_3$ and SiO$_2$. This indicated that under this reaction condition, Al$_2$O$_3$ and SiO$_2$ in fly ash were not fully reduced. When Al and Si were formed, part of Si were reacted with reduced Fe to form corresponding compounds. The content of Si and Al in fly ash was relatively low. The formation and decomposition of carbides might occur in the carbothermal reduction process of alumina and silica.[6] The following reactions were likely to occur:

\[
\begin{align*}
\text{Al}_2\text{O}_3+3\text{C} &= 2\text{Al}+3\text{CO(g)} \\
\text{SiO}_2+2\text{C} &= \text{Si}+2\text{CO(g)} \\
\text{Fe}_2\text{O}_3+\text{SiO}_2+\text{C} &= \text{Fe}_2\text{SiO}_4+\text{CO(g)} \\
\text{Fe}+\text{Si} &= \text{FeSi} \\
\text{Al}_2\text{O}_3+3\text{SiC} &= 2\text{Al}+3\text{Si}+3\text{CO(g)}
\end{align*}
\]
3.3. Phase analysis of carbon reduction fly ash products XRD with carbon content of 1.0 times carbon

Figure 3 was an XRD diagram of the experimental products of extracting silicon and aluminium from fly ash with 1.0 times carbon content. Figure 3 showed that under the reaction conditions of 1.0 times carbon content, 2273K reduction temperature and 30 minutes holding time, the highest peaks of the products were SiC, Fe$_2$SiO$_4$ and Si, which indicated that the crystallinity of these substances was higher. Besides Si, there was also a small amount of Al in the products, which indicated that carbon reduction fly ash could be prepared under these reaction conditions. Silicon and aluminium were also present in the products, which indicated that the carbon content was insufficient.

Major reactions might occur:
\[
\text{SiO}_2 + 2C = \text{Si} + 2\text{CO(g)} \\
\text{Fe}_2\text{O}_3 + \text{SiO}_2 + C = \text{Fe}_2\text{SiO}_4 + \text{CO(g)} \\
\text{Al}_2\text{O}_3 + 3\text{SiC} = 2\text{Al} + 3\text{Si} + 3\text{CO(g)}
\]

Figure 3 XRD pattern of fly ash products reduced by carbon with carbon content of 1.0

Figure 4 XRD pattern of fly ash products reduced by carbon with carbon content of 1.1

3.4. Phase analysis of carbon reduction fly ash products XRD with carbon content of 1.1 times carbon

Figure 4 was an XRD diagram of the experimental products of extracting silicon and aluminium from fly ash with 1.1 times carbon content. Figure 4 showed that the products contained Al, Al$_{1.5}$FeSi, Si, SiC and FeSi$_2$ under the reaction conditions of 1.1 times carbon content, 2273K reduction temperature and 30 minutes heat preservation. This showed that the silicon aluminium alloy could be formed by carbon reduction fly ash under these conditions. Alumina and silicon oxide didn’t exist in the reduction products, which indicated that the reduction temperature and holding time were suitable, and the carbon content was enough to ensure the complete reaction between alumina and silicon oxide. In addition to the target products of Al, Al$_{1.5}$FeSi and Si, impurities of SiC and FeSi$_2$ appeared in the products, which might be related to carbon content, reaction temperature and holding time.
3.5. Phase analysis of carbon reduction fly ash products XRD with carbon content of 1.2 times carbon

Figure 5 XRD pattern of fly ash products reduced by carbon with carbon content of 1.2

Figure 5 was an XRD pattern of the experimental products of extracting silicon and aluminium from fly ash with 1.2 times carbon content. Figure 5 showed that SiC, Si, Al and Al$_{4.5}$FeSi were the products of the experiment under the reaction conditions of 1.2 times carbon content, 2273K reduction temperature and 30 minutes heat preservation. Alumina and silicon oxide were not found in the products, indicating that when the carbon content was 1.2 times that of carbon, the reaction between alumina and silicon oxide was complete. According to the literature[7], in the process of carbon reduction fly ash, adjusting carbon content could reduce the formation rate of silicon carbide, but it could not avoid the formation of silicon carbide in the product. Through the phase composition of the experimental products, it could be inferred that the following reactions might take place under the reaction conditions of Figure 5.

\[
\begin{align*}
\text{Al}_2\text{O}_3 + 3\text{SiC} &= 2\text{Al} + 3\text{Si} + 3\text{CO}(g) \\
\text{SiO}_2 + 2\text{SiC} &= 3\text{Si} + 2\text{CO}(g) \\
\text{SiO}_2 + 3\text{C} &= \text{SiC} + 2\text{CO}(g) \\
\text{Fe}_2\text{O}_3 + 3\text{C} &= 2\text{Fe} + 3\text{CO}(g) \\
4.5\text{Al} + \text{Fe} + \text{Si} &= \text{Al}_{4.5}\text{FeSi}
\end{align*}
\]

4. Conclusion
With charcoal as a reducing agent, the silicon-aluminum alloy can be prepared by carbon reduction fly ash under the condition of reduction temperature of 2273K and heat preservation for 30 minutes. When the carbon content was 0.8 times carbon, the reduction products were Fe$_2$SiO$_4$, SiC, Al$_2$O$_3$ and SiO$_2$, and the carbon content was insufficient to completely reduce the alumina and the silica. When the carbon content was 0.9 times carbon, the reduction products were Al, Si, SiC, Fe$_2$SiO$_4$, FeSi, Al$_2$O$_3$, and SiO$_2$. When the carbon content was 1.0 times carbon, the reduction products were SiC, Fe$_2$SiO$_4$, Si, Al, Al$_2$O$_3$ and SiO$_2$. When the carbon content was 1.1 times carbon, the reduction products were Al, Al$_{4.5}$FeSi, Si, SiC and FeSi. When the carbon content was 1.2 times carbon, the reduction products were SiC, Si, Al, Al$_{4.5}$FeSi. With the increase of carbon content, effects of carbon reduction fly ash to prepare silicon aluminum was better. In this experiment, when the carbon content was 1.2 times carbon, the carbon reduction fly ash had the best effect on the preparation of silicon aluminium alloy.

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