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Effect of Reaction Temperature on Silicon-Aluminum Alloy Prepared from Fly Ash

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Abstract. The effect of carbothermal reduction of fly ash on the preparation of silicon and aluminium at different reaction temperatures was studied. XRD was used to analyze the phase of the reduction products at different reaction temperatures. The results showed that the products of carbothermal reduction fly ash included Al_2O_3, SiC, Al_2SiO_5, $FeSiO_3$ and FeSi at 2073K. At 2123K, the products of carbon reduction fly ash were Al_2O_3, Al_2SiO_5, SiC, FeSi, Si and $Al_{4.5}FeSi$. At 2173K, the main products of carbon reduction fly ash were Al_2O_3, Si, Al, SiC, FeSi and $Al_{4.5}FeSi$. The diffraction peak intensity of silicon at 2173K was higher than that at 2123K, which indicated that increasing the reaction temperature was beneficial to the formation of silicon.Under the reaction conditions of 2223K and 2273K, the kinds of reduction products were the same, which were $Al_{4.5}FeSi$, Si, Al, SiC and FeSi.The intensity of the diffraction peak of aluminium at 2273K was higher than that of aluminium at 2223K, which indicated that increasing the reaction temperature was beneficial to the formation of aluminium. In this experiment, with the increase of temperature, the degree of carbon reduction fly ash was more sufficient and 2273K was the optimum reaction temperature for preparing silicon-aluminium alloy from carbon reduction fly ash.

1. Introduction

Fly ash is a kind of mixed material similar to volcanic ash and it is a solid waste from thermal power generation and urban central heating[1]. Domestic and foreign fly ash is mainly used in construction, highway and agriculture, and a small part of it is used in environmental protection and functional materials[2]. With the development of social economy, the application of fly ash develops to high value-added metallurgical field[3]. In this paper, the effect of reaction temperature on the preparation of silicon-aluminium alloy from fly ash was studied.

2. Test materials and methods

The fly ash of a power plant in Shuicheng was used as raw material, charcoal as reducing agent and wood calcium as binder.The main chemical constituents in fly ash were SiO_2, Al_2O_3, Fe_2O_3, CaO, TiO_2, K_2O, MgO and others, with contents of 45.28%, 23.57%, 11.008%, 4.18%, 3.19%, 1.45%, 1.25%, 10.072%, respectively.The ratio of charcoal to fly ash was 9:20. The quality of wood-calcium was 8% of the total quality of raw material. It was mixed with appropriate amount of water, pelleted and dried. 25AB high frequency infrared induction melting furnace was selected as the reaction equipment. The products of carbon reduction fly ash at different reaction temperatures were analyzed by TD-2500 X-ray diffraction.

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3. Results and discussion

3.1. XRD analysis of fly Ash products from carbon reduction at 2073K

Figure 1 showed that XRD pattern of carbon reduction fly ash products at a reaction temperature of 2073K. As shown in Figure 1 that under the condition of a reduction temperature of 2073 K, the products of the carbothermal reduction fly ash contained Al_2O_3, SiC, Al_2SiO_5, $FeSiO_3$ and FeSi. At 2073K, the carbon-reduced fly ash did not form silicon aluminum alloy, and was formed by aluminum silicate, iron silicon oxide and iron silicon compound. At the reaction temperature of 2073K, the possible reaction between carbon and fly ash was the decomposition of mullite into alumina and silica, the reaction of silica with carbon to form silicon carbide, the reaction of alumina with silica to form aluminum silicate. Iron oxide and silicon oxide reacted to form ferrosilicon and iron silicate.The Al_2O_3 phase in the reduced products of Figure 1 indicated that the degree of carbon reduction fly ash reaction was insufficient at the reaction temperature of 2073K, which might be due to the fact that the alumina was not sufficiently reduced due to the low reaction temperature.When the temperature was below 2073K, alumina hardly participated in the chemical reaction[4].

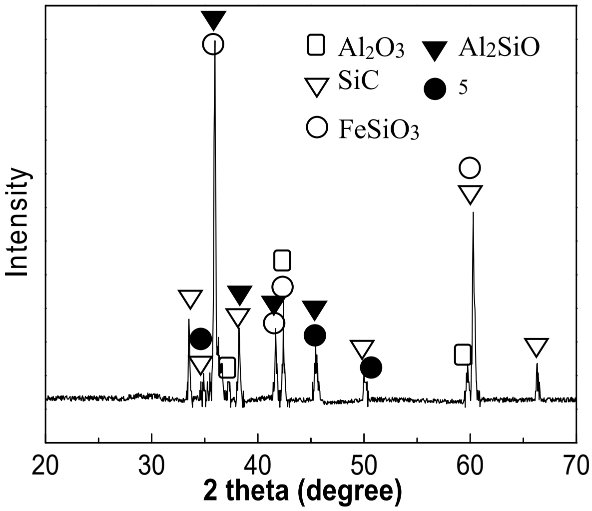

Figure 1. XRD pattern of fly ash products reduced by carbon at 2073K

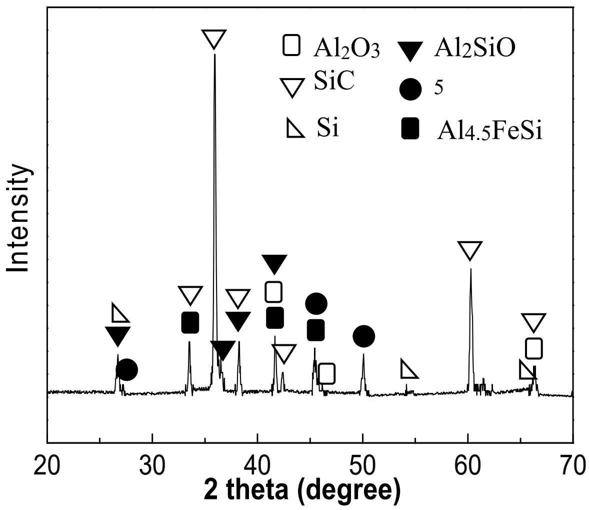

Figure 2. XRD pattern of fly ash products reduced by carbon at 2123K

3.2. XRD analysis of fly Ash products from carbon reduction at 2123K

Figure 2 showed that XRD pattern of carbon reduction fly ash products at a reaction temperature of 2123K. As shown in Figure 2 that under the reaction conditions of reduction temperature of 2123 K, the products of carbon reduction fly ash were Al_2O_3, Al_2SiO_5, SiC, FeSi, Si and $Al_{4.5}FeSi$. Silicon-aluminum alloy, silicon, and silicon carbide, aluminum silicate, ferrosilicon and alumina were formed in the carbon-reduced fly ash at 2123K. The presence of Al_2O_3 in the reduced product of Figure 2 indicated that the reaction of carbon with alumina was insufficient at the reaction temperature of 2123 K, possibly due to the fact that the alumina was not sufficiently reduced due to the low reaction temperature.

Figure 2 was compared with Figure 1, the diffraction peak intensity of Al_2O_3 was decreased, indicating that the amount of Al_2O_3 in the reduction products was small at the reduction temperature of 2123K, and the increase of the reduction temperature was favorable for carbon reduction of alumina. At 2123K, carbon-reduced fly ash could produce silicon-aluminum alloy and elemental silicon. Comparing Figure 1 with Figure 2, it was concluded that the reduction temperature of the carbon reduction fly ash was increased, which was beneficial to the reaction of carbon with silicon oxide and alumina to form silicon and silicon aluminum alloy.

3.3. XRD analysis of fly Ash products from carbon reduction at 2173K

Figure 3 showed that XRD pattern of carbon reduction fly ash products at a reaction temperature of 2173K. As shown in Figure 3, under the reaction conditions of reduction temperature of 2173 K, the products of carbon reduction fly ash mainly included Al_2O_3, Si, Al, SiC, FeSi and $Al_{4.5}FeSi$. Silicon-aluminium alloy, silicon, aluminium and other target products were produced in fly ash by carbon reduction at 2173K. It also included silicon carbide, ferrosilicon, ferrosilicon-aluminium and alumina. At 2173K reaction temperature, mullite decomposed into alumina and silica, carbon reduces silicon oxide to form silicon carbide, carbon reacted with silicon oxide and alumina to form silicon aluminum alloy, iron oxide and silicon oxide formed ferrosilicon, carbon and oxidation Silicon produced silicon, and carbon and aluminum formed aluminum.Christoph Kemper suggested that the presence of silicon oxide could effectively reduce the formation of carbides in aluminium[5].

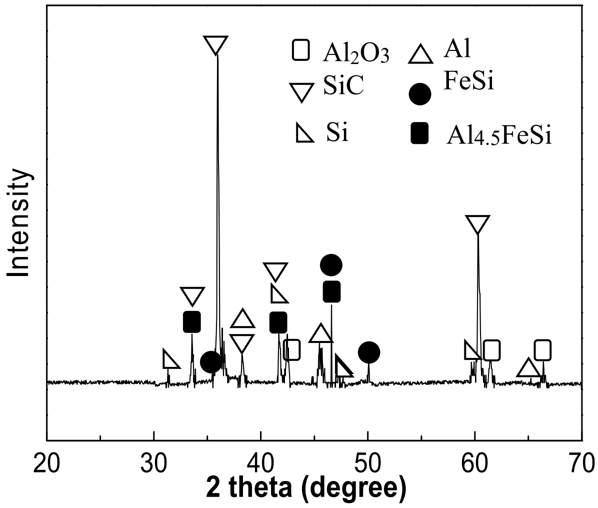

Figure 3. XRD pattern of fly ash products reduced by carbon at 2173K

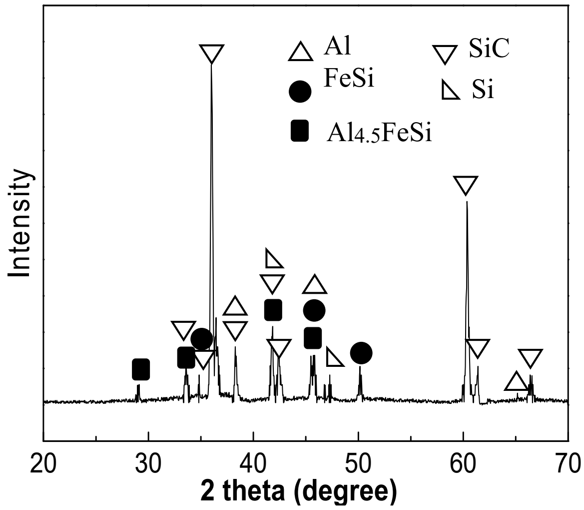

Figure 4. XRD pattern of fly ash products reduced by carbon at 2223K

As shown in Figure 3 that Al_2O_3 was present in the reduced product, indicating that the alumina did not fully participate in the reaction under the reaction condition of 2173K, which might be due to insufficient carbon content or too low a reaction temperature, so that the alumina was not sufficiently involved in the reaction. Compared with Figure 2, when the reduction temperature reached 2173K, aluminum was newly formed in the reduced products, and aluminum silicate was not formed, indicating that the elevated temperature was favorable for carbon reduction of alumina to form aluminum. The intensity of the diffraction peak of silicon in Figure 3 was higher than the intensity of the diffraction peak of silicon in Figure 2, indicating that the amount of silicon in the products increasesd at a reaction temperature of 2173 K, and raising the reaction temperature was favorable for the formation of silicon. Under 2173K condition, carbon-reduced fly ash could form silicon-aluminum alloy. Comparing Figure1, Figure 2 and Figure3, it was concluded that the reduction temperature of the carbon reduction fly ash was increased, which was beneficial to the reaction of carbon with silicon oxide and alumina to form silicon, aluminum and silicon aluminum alloy.

3.4. XRD analysis of fly Ash products from carbon reduction at 2223K

Figure 4 was an XRD pattern of the carbon reduced fly ash products at a reaction temperature of 2223K. As shown in Figure 4, the reduction products were $Al_{4.5}FeSi$, Si, Al, SiC and FeSi under the reaction condition of a reduction temperature of 2223 K. The target products of silicon aluminum alloy, silicon, aluminum and the like was formed in the carbon reduction fly ash at 2223 K; the impurities in the products contained silicon carbide, ferrosilicon; no alumina was found in the products. At a reduction temperature of 2223 K, alumina was fully involved in the reaction. Compared with Figure 3 and Figure 4 , when the reduction temperature reached 2223 K, the alumina in the reduced products disappeared, indicating that the elevated temperature favored the alumina to be sufficiently reduced.

The intensity of the diffraction peak of aluminum in Figure 4 was higher than the intensity of the diffraction peak of aluminum in Figure 3, indicating that the amount of aluminum in the product increased at the reaction temperature of 2223 K, and the increase of the reaction temperature was favorable for the formation of aluminum. Comparing Figure 1,Figure 2, Figure 3 and Figure 4, it was found that raising the reaction temperature was beneficial to the reaction of carbon with fly ash to form aluminum, silicon and silicoalumino compounds.

3.5. XRD analysis of fly Ash products from carbon reduction at 2273K

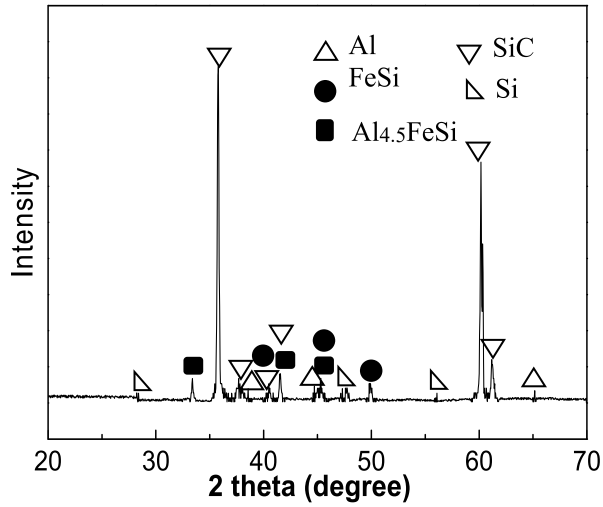

Figure 5 XRD pattern of fly ash products reduced by carbon at 2273K

Figure 5 showed that XRD pattern of carbon reduction fly ash products at a reaction temperature of 2273K. Under the reaction conditions of a reduction temperature of 2273 K, the reduction products were Si, $Al_{4.5}FeSi$, Al, FeSi and SiC. Figure 5 was the same as the type of reduction products in comparison with Figure 4. The intensity of the diffraction peak of aluminum in Figure 5 was higher than the intensity of the diffraction peak of aluminum in Figure 4, indicating that the amount of aluminum in the products increased at the reaction temperature of 2273 K, and the increase of the reaction temperature was favorable for the formation of aluminum. Comparing Figure1, Figure 2, Figure 3, Figure 4 and Figure 5, it was found that raising the reaction temperature was beneficial to the reaction of carbon and fly ash more fully to form aluminum, silicon and silicoalumino compounds.

4. Conclusion

The products of carbothermal reduction fly ash included Al_2O_3, SiC, Al_2SiO_5, $FeSiO_3$ and FeSi at 2073K. At 2123K, the products of carbon reduction fly ash were Al_2O_3, Al_2SiO_5, SiC, FeSi, Si and $Al_{4.5}FeSi$. At 2173K, the main products of carbon reduction fly ash were Al_2O_3, Si, Al, SiC, FeSi and $Al_{4.5}FeSi$. The diffraction peak intensity of silicon at 2173K was higher than that at 2123K, which indicated that increasing the reaction temperature was beneficial to the formation of silicon.Under the reaction conditions of 2223K and 2273K, the kinds of reduction products were the same, which were $Al_{4.5}FeSi$, Si, Al, SiC and FeSi.The intensity of the diffraction peak of aluminium at 2273K was higher than that of aluminium at 2223K, which indicated that increasing the reaction temperature was beneficial to the formation of aluminium. In this experiment, with the increase of temperature, the degree of carbon reduction fly ash was more sufficient and 2273K was the optimum reaction temperature for preparing silicon-aluminium alloy from carbon reduction fly ash.

Acknowledgments
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