A Synthesis Technology of Honeycomb-Like Structure MnO₂ from Low Grade Manganese Ore

Abstract

In this paper, the honeycomb-like structure MnO₂ was firstly prepared from low grade manganese ore with three main steps. Firstly, low grade manganese ore was reduced to be MnO by biomass at 400 °C in 40 min. Secondly, the soluble MnO from the reduced low grade MnO ore was leached by dilute sulphuric acid to be MnSO₄ solution at 80 °C in 30 min, and lastly the honeycomb-like structure MnO₂ can be prepared by the redox reaction of mixed MnSO₄ and KMnO₄ solution. The optimal experimental conditions were that the pH value of mixed solution was 5, the reaction temperature was 60 °C, the mole ration of KMnO₄ and MnSO₄ was 2.5:3, the feed rate of KMnO₄ and MnSO₄ solution was 3 ml/min until they were feed out, and then kept for 30 min before filtrating. The final product was characterized by X-ray diffraction (XRD) and scanning electron microscope (SEM), demonstrating that its crystal structure was γ-MnO₂.

Keyword: MnO₂; Honeycomb-like structure; Manganese ore; Demonstrating; Redox reaction; Microstructure

Introduction

Manganese ore is important mineral resource, widely being used in various industries which include metallurgy, ceramics, pharmaceuticals etc. According to USGS statistics [1] the base reserve of manganese ore in the world is about 5 billion 700 million ton mainly in South Africa (71.8%), Ukraine (11.9%), Australia (3.8%), and China (2.5%). The total amount of China’s manganese resource is abundant, but which have the characteristics of larger lean ore, little mine with rich grade and complicated ore type. Since the availability of high-grade manganese ore is limited, it is imperative to identify and process low-grade complex ores that don’t adversely impact the environment [2-4].

During the past few decades, controllable synthesis of specific microstructure materials has received considerable attention for their unique properties and potential applications in functional materials [5-8]. The growing interest has been focused on nanostructures MnO₂ because of their fundamental scientific significance and many technological applications [9-11]. These specific nanostructures with outstanding performance and unique chemical properties have been used extensively in various kinds of energy storage systems. The different structure MnO₂ were prepared successfully on the basis of the redox reactions of MnO₄⁻ and/or Mn²⁺, such as hydrothermal Golden DC & Shen YF [12-14], coprecipitation Lee HY & Staiti P [15,16], thermal Muraoka Y [17], sol-gel [18-20], and electrochemical methods etc [21,22].

Among these researches, few studies have been done that the manganese ore as raw materials was used to prepare nanostructure manganese oxides. In this paper, the honeycomb-like structure MnO₂ has been successfully prepared from low grade manganese ore. Low grade manganese ore was firstly reduced to be dissolvable MnO by biomass at 400 °C; the reduction product was leached with diluted sulfuric acid to be MnSO₄ solution at 80 °C in 30 min, and lastly the honeycomb-like structure MnO₂ can be prepared by the redox reaction of mixed MnSO₄ and KMnO₄ solution. The optimal experimental conditions were that the pH value of mixed solution was 5, the reaction temperature was 60 °C, the mole ratio of KMnO₄ and MnSO₄ was 2.5:3, the feed rate of KMnO₄ and MnSO₄ solution was 3 ml/min until they were feed out, and then kept for 30 min before filtrating. The final product was characterized by X-ray diffraction (XRD) and scanning electron microscope (SEM), demonstrating that its crystal structure was γ-MnO₂.

Experimental Section

Chemical analysis of low grade manganese ore and the final product

The low-grade manganese oxide ore was selected from Guangxi, South China. Its main chemical composition is shown in Table 1. In contrast to the raw ore, the Mn content of the prepared honeycomb-like MnO₂ was increased greatly to be 57.05%, and other impurity content is very low.

Table 1: Chemical composition of low grade manganese oxide ore and honeycomb-like MnO₂ (mass fraction).

<table>
<thead>
<tr>
<th>Component</th>
<th>Mn</th>
<th>Zn</th>
<th>Ni</th>
<th>Pb</th>
<th>Co</th>
<th>Cu</th>
<th>Fe</th>
<th>Mg</th>
<th>Cr</th>
<th>Al</th>
<th>Si</th>
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</thead>
<tbody>
<tr>
<td>Manganese Ore/%</td>
<td>17.32</td>
<td>0.017</td>
<td>0.05</td>
<td>0.25</td>
<td>0.057</td>
<td>0.041</td>
<td>11.77</td>
<td>0.19</td>
<td>11.3</td>
<td>2.559</td>
<td>14.6</td>
</tr>
<tr>
<td>Honeycomb-Like MnO₂/%</td>
<td>57.05</td>
<td>0.003</td>
<td>0.01</td>
<td>0.01</td>
<td>0.059</td>
<td>0.002</td>
<td>0.265</td>
<td>0.007</td>
<td>0.004</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Experiment procedure

The preparation of MnSO₄ solution from low grade manganese: The mixture of manganese dioxide ore and sawdust were well-mixed and put into ceramic crucible, and then were roasted in muffle furnace (the sawdust dosage was 25% mass fraction of manganese ore, the roasting temperature was 400 °C and roasting time was 30 min) and hermetically cooled to room temperature before removing the cover. The reduced manganese ore was leached by 1 mol/L sulfuric acid solution for 30 min at 80 °C, the ratio of sulfuric acid and reduced manganese ore is controlled at 10 ml/g. The MnSO₄ solution can be obtained after filtrating the leached manganese ore and washing it by deionized water, using as raw liquid for preparing the honeycomb-like structure MnO₂, the content of MnSO₄ solution is 0.576 mol/L.

The preparation of the honeycomb-like structure MnO₂: A certain amount of KMnO₄ solution and the MnSO₄ solution were feed into three necks flask by a peristaltic bump, and the flask was put in 80 °C water bath. The honeycomb-like structure MnO₂ product was obtained by washing, filtrating and drying at 80 °C in drying oven. The crystal structure and the morphology were characterized by X-ray diffraction and Scanning Electron Microscopy. The Schematic diagram of the preparing process for honeycomb-like MnO is shown in Figure 1.

Result and discussion

The effect of pH value

The flask with three necks was put into water bath with 60 °C constant temperature. MnSO₄ solution was adjusted to the different pH value of 3, 4, 5, 6, 7 by adding NaOH particle, and then MnSO₄ and KMnO₄ solution with the mole ratio of 3:2 were added into flask at the same speed of 3 ml/min. The MnO₂ content of the precipitate was shown in Figure 2. When the pH value of MnSO₄ solution was increased to be 5, MnO₂ content of the precipitate can be reached to be 94.24%. When the reduced MnO₂ ore was leached by dilute sulfuric acid to be MnSO₄, other impurity ions such as Fe²⁺, Al³⁺, and Zn²⁺ was solved. Some ions were precipitated if pH value of MnSO₄ solution was increased to be 5, so the purity MnO₂ product was improved. When pH value of MnSO₄ solution was improved to be over 6, the precipitated Al(OH)₃ was dissolved again in the MnSO₄ solution, resulting in the decrease of the purity MnO₂ product.

The effect of reaction temperature

The pH value of MnSO₄ solution was adjusted to be 5 by adding NaOH particle. The flask with three necks was put into water bath with the different temperature and then MnSO₄ and KMnO₄ solution with the mole ratio of 3:2 were added into flask at the same speed of 3 ml/min. The MnO₂ content of the precipitate was shown in Figure 3. With the increase of water bath temperature, the purity of the MnO₂ product was improved gradually. When the reaction temperature ranged from 60 °C to 90 °C, the purity of MnO₂ product was increased from 94.24% to be 94.3%. At the relative high reaction temperature, the rate of chemical reaction was accelerated. However, in consideration of water evaporation at 90 °C, the temperature of water bath was controlled at 60 °C.

The effect of the molar ratio of KMnO₄ and MnSO₄

The pH value of MnSO₄ solution was adjusted to be 5 by adding NaOH particle. The flask with three necks was put into water bath with 60 °C and then MnSO₄ and KMnO₄ solution with the different
mole ratio were separately added into flask at the same speed of 3 ml/min. The MnO₂ content of the precipitate was shown in Figure 4. With the decrease of mole ratio of KMnO₄ and MnSO₄, the content of the product raised at first and then descended. The optimal mole ratio of KMnO₄ and MnSO₄ is 2.5:3, and the purity of MnO₂ is 95.01%.

The effect of the flux velocity of KMnO₄ and MnSO₄

The pH value of MnSO₄ solution was adjusted to be 5 by adding NaOH particle. The flask with three necks was put into water bath with 60 °C and then KMnO₄ and MnSO₄ solution with the mole ratio of 2.5:3 were added into flask at the speed of 2, 3, 4, 5, 6 ml/min. The MnO₂ content of the precipitate was shown in Figure 5. With the increase of MnSO₄ and KMnO₄ solution feed rate, the purity of MnO₂ product was decreased. When the feed rate was improved to be over 5, the purity of MnO₂ product was decreased slowly. When the feed rate was relative fast, partial solution of MnSO₄ and KMnO₄ did not occur redox reaction which causing the decrease of MnO₂ precipitation, and the content of the impurity in product was relative high. So the feed rate 3 ml/min of MnSO₄ and KMnO₄ solution was recommended.

XRD analysis of the honeycomb-like structure MnO₂

The crystal phase of the honeycomb-like structure MnO₂ was analyzed by powder X-ray diffraction. The XRD patterns of the representative a product was shown in Figure 7, it corresponded to the formation of γ-MnO₂ (ICDD-JCPDS No. 14-0644). Meanwhile, the broadened diffraction peaks indicated that the crystalline sizes of the samples was small, further verifying the high crystallinity of the MnO product.

SEM characterization of the honeycomb-like structure MnO₂

The morphology of the prepared sample is characterized
by SEM. Figure 8a shows the characteristic SEM images of honeycomb-like structure MnO, demonstrating that the prepared product consists of honeycomb-like structure MnO. Figure 8b shows the magnified image of honeycomb-like structure MnO and many holes can be seen clearly on the MnO product surface.

Conclusion

Honeycomb-like structure γ-MnO is prepared from low grade manganese ore by a technology including three main procedures: reduction of low grade manganese, leaching process of the reduced manganese ore, oxidation-reduction process of MnSO₄ and KMnO₄ solution. The reduction process of manganese ore is finished in 40min at 400 °C, the leaching process is carried out in 80 °C water bath in 30min, and honeycomb-like structure MnO product is eventually prepared by oxidation-reduction process of MnSO₄ and KMnO₄ solution with the experimental conditions of the solution pH 5, reaction temperature of 60 °C, flux velocity of 3ml/min, the mole ratio of 2.5:3 and the standing time of 30min.

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Conflict of Interest

The authors declare, that there is no conflict of interest.

References
