Research Article

Fabrication of Nano-CeO$_2$ and Application of Nano-CeO$_2$ in Fe Matrix Composites

Wang Tiebao, Cui Chunxiang, Wang Xiaodong, and Li Guobin

School of Material Science and Engineering, Hebei University of Technology, Tianjin, 300132, China

Correspondence should be addressed to Wang Tiebao, gdwtb@126.com

Received 18 May 2010; Accepted 26 August 2010

Academic Editor: Kin Tak Lau

Copyright © 2010 Wang Tiebao et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

It is explicated that nano-CeO$_2$ is fabricated by the direct sedimentation method. The components and particles diameter of nano-CeO$_2$ powders are analyzed by XRD and SEM. The thermodynamic analysis and acting mechanism of nano-CeO$_2$ with Al in Fe matrix composites are researched, which shows that the reaction is generated between CeO$_2$ and Al in the composite, that is, $3\text{CeO}_2 + 4\text{Al} \rightarrow 2\text{Al}_2\text{O}_3 + 3[\text{Ce}]$, which obtains Al$_2$O$_3$ and active [Ce] during the sintering process. The active [Ce] can improve the performance of CeO$_2$/Fe matrix composites. The suitable amount of CeO$_2$ is about 0.05% in CeO$_2$/Fe matrix composites. SEM fracture analysis shows that the toughness sockets in nano-CeO$_2$/Fe matrix composites are more than those in no-added nano-CeO$_2$ composites, which can explain that adding nano-CeO$_2$ into Fe matrix composite, the toughness of the composite is improved significantly. Applied nano-CeO$_2$ to Fe matrix diamond saw blades shows that Fe matrix diamond saw blade is sharper and of longer cutting life than that with no-added nano-CeO$_2$.

1. Foreword

Nanometer particle is physical dimensions of particle in 1~100 nm whose possessive space is between an atom and a macrscopical substance. The scientific researches of nanometer material have been one of the interesting researches in chemistry, physics, and material science fields. Due to the surface effect, the less size effect, the quanta size effect, the tunnel effect and so on, nanocomposites have many especial characteristics, which has extensive applied foreground.

In China there are resourceful rare-earth elements which possess 43% of world reserves. In the rare-earth elements the prices of cerium are lower, and its applications are the most comprehensive.

In this paper, preparation method of CeO$_2$ nanopowder is investigated. And the intention is that CeO$_2$ nanopowder is applied to diamond saw blades.

2. Preparation Method of CeO$_2$ Nanopowder

So far preparation method of CeO$_2$ nanopowder includes mainly flux method [1], solid state reaction method [2], direct sedimentation or agglomerating method [3], sonochemical synthesis method [4], sol-gel method [5], microemulsion method [6, 7], gas condensation method [8], and so on.

2.1. Preparation Principium of CeO$_2$ Nanopowder. The investigation has used agglomerating method to prepare CeO$_2$ nanopowder. Preparation principium of CeO$_2$ nanopowder is as follows.

The deionized water solution with 0.1 mol·L$^{-1}$ Ce(NO$_3$)$_3$·6H$_2$O is prepared, whereafter the deposition solvent of 0.1 mol·L$^{-1}$ (NH$_4$)$_2$CO$_3$·H$_2$O is acceded to the mother solution which reacts as follows:

$$3(\text{NH}_4)_2\text{CO}_3 \cdot \text{H}_2\text{O} + 2\text{Ce(NO}_3)_3 \cdot 6\text{H}_2\text{O} \rightarrow \text{Ce}_2(\text{CO}_3)_3 \cdot 8\text{H}_2\text{O} + 6\text{NH}_4\text{NO}_3 + 7\text{H}_2\text{O}$$

To get hold of colloid solution by the reaction, the colloid solution is filtrated in vacuum. For the sake of wiping off impurities and preventing conglomeration of nanopowder in later heat treatment, the filtrated cake is washed repeatedly with deionized water or ethanol. The deionized water solution or ethanol solution is dispersed by ultrasonic,
which gets quadratic colloid solution. The quadratic colloid solution is filtrated, which obtains prophase powder. The prophase powder is dried at 300°C for 1 hour in drying machinery, in which the reaction is as follows:

$$2\text{Ce}_2(\text{CO}_3)_3 + \text{O}_2 = 4\text{CeO}_2 + 6\text{CO}_2$$  \hspace{1cm} (2)

Thereby CeO$_2$ nanopowder is acquired.

2.2. Analysis of Components and Grains Size on CeO$_2$ Nanopowder. Figure 1 is the analyse result of prepared nanopowder by X-ray diffraction. Figure 1 shows that prepared nanopowder is CeO$_2$.

Preparing powder desired to obtain nanometer size, two essential conditions must be satisfied.

(1) In the processes of nucleation and growth, nucleation velocity as well as growth speed must be controlled.

(2) In prepared solution process, the convergence effect of grain must be controlled. The method is as follows.

Adding PEG600 in the solution, formed Ce$_2$(CO$_3$)$_3$ grains are enwrapped by PEG600 molecules, which avoids the aggregation of Ce$_2$(CO$_3$)$_3$ grains.

In addition the effect parameters of prepared CeO$_2$ nanopowder involve yet reaction temperature and times, drying temperature and times, and the kinds of added surface activing agent.

Figure 2 is the analysis result of TEM on prepared CeO$_2$ nanopowder.

From Figure 1 it can be descried that CeO$_2$ nanopowder is batt shape, whose size is about 20 nm.

3. Fabrication and Properties Analysis of CeO$_2$/Fe Matrix Composite

3.1. Fabrication and Properties Analysis of CeO$_2$/Fe Matrix Composite. CeO$_2$ nanopowder glue water solution (or ethanol solution) must be dispersed by ultrasonic before CeO$_2$/Fe matrix composites are fabricated. Whereafter Fe, Cu, Al, Sn, and CeO$_2$ nanopowder are mixed by design content. The powders are grinded by ball milling into symmetrical powder, so composite samples are finally pressed and sintered by hot-press.

The sintering of CeO$_2$/Fe matrix composites can be divided into five stages.

(1) In the first stage, sintering temperature is less than 400°C. In this stage, laigh melting-point metals begin to melt. The surface oxides of metal grain are deoxidized by aluminum, and the adsorbent gas around metal grain begins to be eliminated at one time. In this stage, squeeze play is too large to prevent spilling of laigh melting point metals. The squeeze play to samples is popularly 0.8 MPa in the stage.

(2) In the second stage, the sintering is at 400°C by squeeze play 1.2 MPa. The intent added squeeze play is mainly to eliminate the volatilization gas of liquid olefin.

(3) In the third stage, 400°C up to sintering temperature (800°C), the content of liquid phase increases along with the temperature raise. The fine grains and raised part of grains will be melted. Solid grains will arrange renewedly and remanent gas will be eliminated ulteriorly. In this stage, squeeze play to samples is 1.2 MPa to 2 MPa.

(4) Fourth stage, that is, heat preservation stage in which squeeze play to samples keeps at 2 MPa all the way. In this stage, alloy elements want to diffuse and dissolve reciprocally, which forms solid solution. And the reaction between CeO$_2$ and Al is as follows:

$$3\text{CeO}_2 + 4\text{Al} = 2\text{Al}_2\text{O}_3 + 3[\text{Ce}]$$  \hspace{1cm} (3)

CeO$_2$ reacts with aluminum to produce active [Ce] and nano-Al$_2$O$_3$ during the sintering. The active [Ce] can be adsorbed at surface of solid grain, which debases interfacial tension of grains to increase the adhesional wetting between solid grains and liquid state metal, to enhance hardness and strength of materials.
3.2. The Properties of CeO$_2$/Fe Matrix Composite. Figure 3 shows the effect of CeO$_2$ content on the hardness (HRB) and bending strength of Fe matrix composites. From Figure 3 it can be seen that the hardness and bending strength of Fe matrix composites attain the most value when the CeO$_2$ content is 0.05%wt, whose content is clearly less. Because CeO$_2$ can react with aluminum to produce active [Ce], such as front depiction, [Ce] can increase felting strength among grains. The remnant less CeO$_2$ can play a complementarity strength part. But more CeO$_2$ is able to become impure, which can cause brittleness increasing of material.

3.3. Fabrication and Properties Analysis of CeO$_2$/Fe Matrix Composite. The relation between $\Delta G^0$ of oxides such as CuO, FeO, NiO, Al$_2$O$_3$, CeO$_2$, and Ce$_2$O$_3$ and temperature are shown in Figure 4, whose test condition is at 800°C for 5 minutes and squeeze play to samples is 2 MPa.

Figure 4 shows that the standard creating free enthalpy $\Delta G^0$ of Ce$_2$O$_3$ is the lowest at the same temperature. $\Delta G^0$ of Al$_2$O$_3$ is higher than that of Ce$_2$O$_3$ but is lower than that of CeO$_2$, which indicates that CeO$_2$ can be deoxidized by aluminium to form active [Ce] and Al$_2$O$_3$ as formula (3).

3.4. Fabrication and Properties Analysis of CeO$_2$/Fe Matrix Composite. Figure 5 shows the elements distributing in CeO$_2$/Fe matrix composite, whose distributing is not symmetrical because the composites are fabricated by powder metallurgy process. It is important to note that there is no oxygen with Ce displaying at the peak value, indicating that CeO$_2$ can reacts with aluminium to produce active [Ce].
Figure 6 shows X-ray analysis result. There are Al₂O₃ and Ce in CeO₂/Fe matrix composite, which explains that the reaction between CeO₂ and aluminum is capable of occurring, that reaction is shown in formula (3).

For workout, the more CeO₂ (0.5%wt) is added to CeO₂/Fe matrix composite, so there is CeO₂ in Figure 6.

3.5. Fabrication and Properties Analysis of CeO₂/Fe Matrix Composite. Figure 7 is SEM photograph of samples fracture on CeO₂/Fe matrix composites. Figures 7(a) and 7(b) show that there are more dimples in added CeO₂ Fe matrix composite than in no-added CeO₂ one, which shows that CeO₂/Fe matrix composite has higher toughness than Fe matrix composite. It is perhaps because CeO₂ can be deoxidized by aluminium to form active [Ce] which can nail on the dislocation, which can obtain the fine crystalline grin under sintering.

4. The Application of Nano-CeO₂/Fe Matrix Composite on Diamond Saw Blade

Figure 8 is the out-edge height of diamond. Applying nano-CeO₂ to Fe matrix diamond saw blades, the result obtained from Figure 8 shows that the out-edge height of diamond added nano-CeO₂ is higher than that of no-adding nano-CeO₂ in edges of diamond saw blade. And so the diamond saw blade added nano-CeO₂ is sharper.

<table>
<thead>
<tr>
<th>Kind of diamond saw blades</th>
<th>Holding strength (MPa)</th>
<th>Cutting speed (m/minute)</th>
<th>Cutting life (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-added nano-CeO₂</td>
<td>566</td>
<td>30.5</td>
<td>3450</td>
</tr>
<tr>
<td>Added nano-CeO₂</td>
<td>624</td>
<td>39.8</td>
<td>3475</td>
</tr>
</tbody>
</table>

The characteristics of different diamond saw blades are shown in Table 1. Investigation shows that the holding strength of matrix to diamond for adding nano-CeO₂ is 58 MPa higher than that for no-adding nano-CeO₂. So under the same condition of cutting life, added nano-CeO₂ diamond saw blade is clearly sharper than the no-adding nano-CeO₂ one.
5. Conclusions

(1) The investigation used agglomerating method to prepare CeO\textsubscript{2} nanopowder. Preparation principium of CeO\textsubscript{2} nanopowder is as follows:

\[ 3(\text{NH}_4)_2\text{CO}_3 \cdot \text{H}_2\text{O} + 2\text{Ce(NO}_3\text{)}_3 \cdot 6\text{H}_2\text{O} \]
\[ = \text{Ce}_2(\text{CO}_3\text{)}_3 \cdot 8\text{H}_2\text{O} \downarrow + 6\text{NH}_4\text{NO}_3 + 7\text{H}_2\text{O} \]

In the dryness process at 300°C for 1 hour, the reaction creates CeO\textsubscript{2} nanopowder as follows:

\[ 2\text{Ce}_2(\text{CO}_3\text{)}_3 + \text{O}_2 = 4\text{CeO}_2 + 6\text{CO}_2 \uparrow \]

CeO\textsubscript{2} nanopowder is of batt shape, whose size is about 20 nm.

(2) In the sintering process at 800°C for 5 minutes, CeO\textsubscript{2} in the matrix is deoxidized by aluminium which creates active \([\text{Ce}]\). The reaction is as follows:

\[ 3\text{CeO}_2 + 4\text{Al} \rightarrow 2\text{Al}_2\text{O}_3 + 3[\text{Ce}] \]

to produce active \([\text{Ce}]\) and nano-\text{Al}_2\text{O}_3.

(3) Applied nano-CeO\textsubscript{2} to Fe matrix diamond saw blades shows that Fe matrix diamond saw blades is sharper and of longer cutting life than on-adding nano-CeO\textsubscript{2}.

Acknowledgments

The authors gratefully acknowledge the contribution of the Testing Center. This research was carried out within the Key Technology R&D Program of Hebei Province.

References


Submit your manuscripts at http://www.hindawi.com