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Research Article

Fabrication of Nano-CeO_2 and Application of Nano-CeO_2 in Fe Matrix Composites

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It is expatiated 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, $3CeO_2+4Al \rightarrow 2Al_2O_3+3[Ce]$, which obtains Al_2O_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 macroscopical 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 $0.1\,\mathrm{mol}\cdot\mathrm{L}^{-1}$ $Ce(NO_3)_3 \cdot 6H_2O$ is prepared, whereafter the deposition solvent of $0.1\,\mathrm{mol}\cdot\mathrm{L}^{-1}$ $(NH_4)_2CO_3 \cdot H_2O$ is acceded to the mother solution which reacts as follows:

$$3(NH_4)_2CO_3 \cdot H_2O + 2Ce(NO_3)_3 \cdot 6H_2O = Ce_2(CO_3)_3 \cdot 8H_2O \downarrow + 6NH_4NO_3 + 7H_2O \quad (1)$$

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,

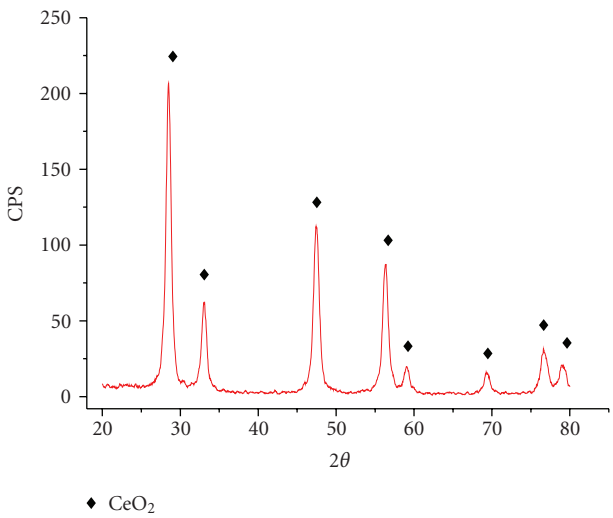


Figure 1: X-ray diffraction analysis of fabricated CeO_2 nanopowder.

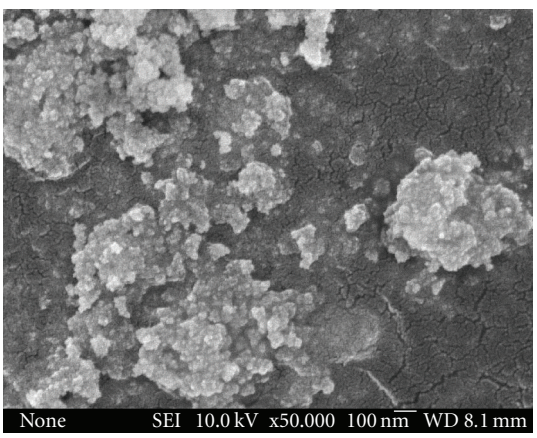


Figure 2: TEM photograph of CeO_2 nanopowder.

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:

$$2Ce_2(CO_3)_3 + O_2 = 4CeO_2 + 6CO_2 \uparrow \quad (2)$$

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:

$$3CeO_2 + 4Al = 2Al_2O_3 + 3[Ce]. \quad (3)$$

CeO_2 reacts with aluminum to produce active [Ce] and nano-Al_2O_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.

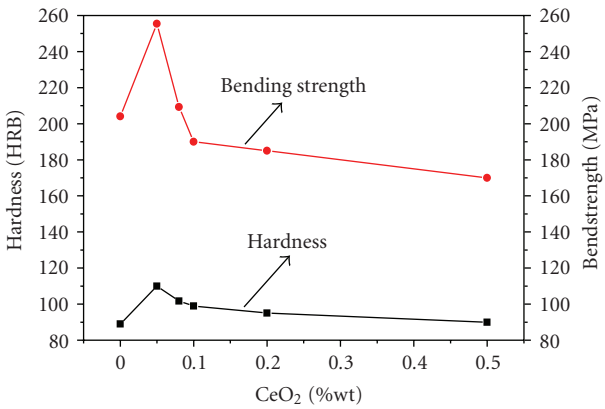


Figure 3: The effect of CeO_2 content on the hardness and bending strength of Fe matrix composites. (The samples size of bending test is 40 mm×10 mm×3 mm.)

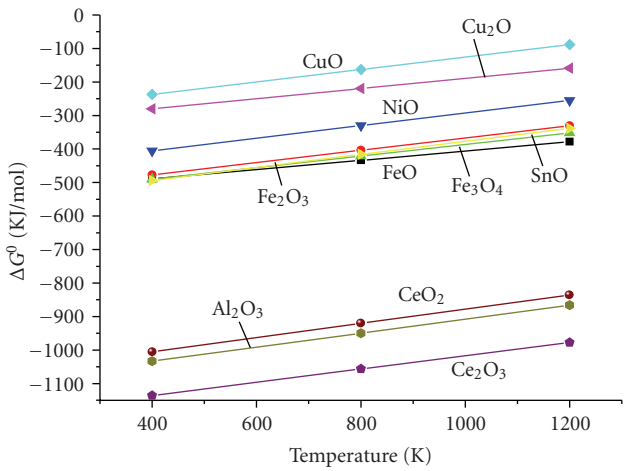


Figure 4: Relationship between ΔG^0 and T.

(5) In the fifth stage, that is, cooling stage, sintered samples are air cooling. When samples temperature is lower than 300°C, the sintered samples can be taken out from the mold of hot-press.

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 ΔG^0 of oxides such as CuO, FeO, NiO, Al_2O_3, CeO_2, and Ce_2O_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 ΔG^0 of Ce_2O_3 is the lowest at the same temperature. ΔG^0 of Al_2O_3 is higher than that of Ce_2O_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_2O_3 as formula (3).

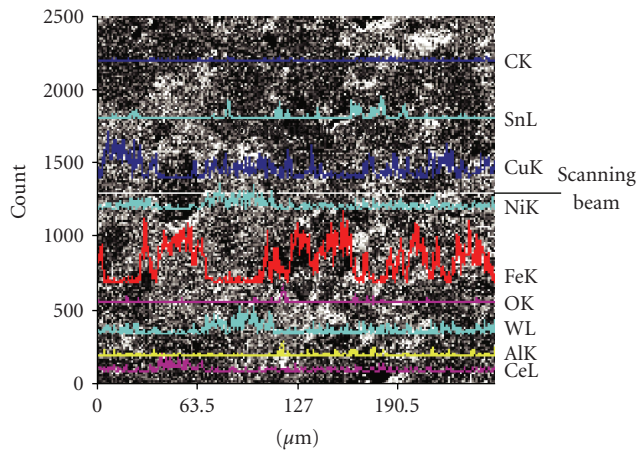


Figure 5: The liner distribution analysis of elements on Fe matrix composite to which 0.5%wt nano-CeO_2 was added.

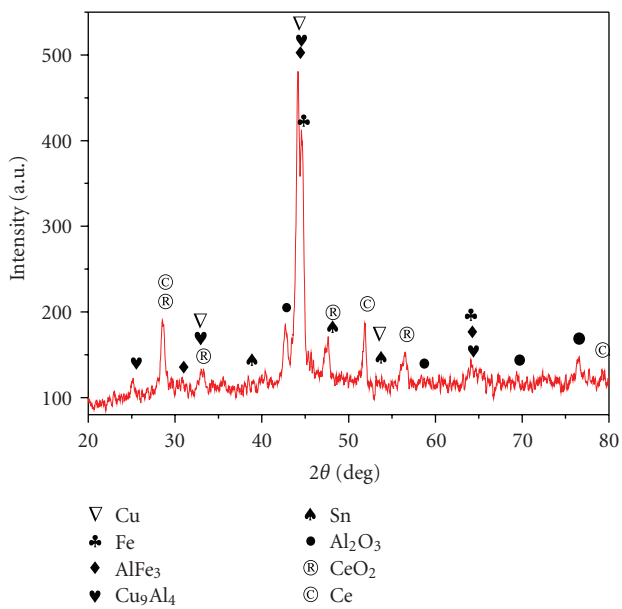
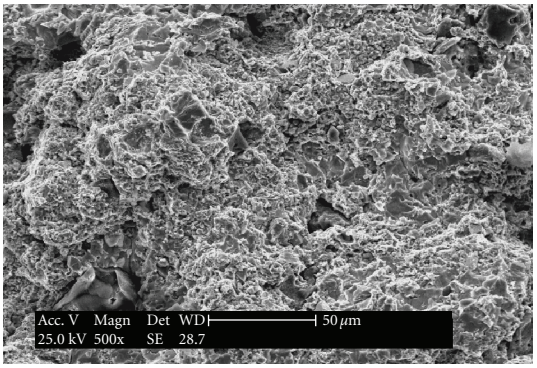
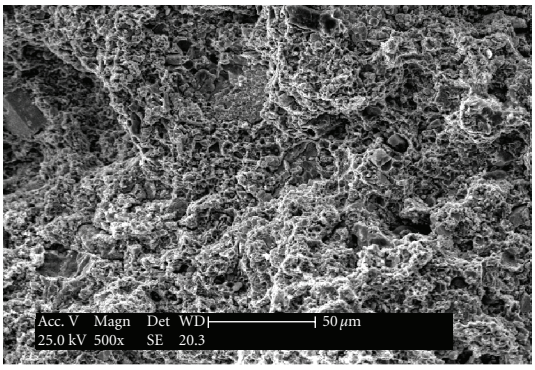


Figure 6: X-ray analysis of nano-CeO_2/Fe matrix composite.

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].

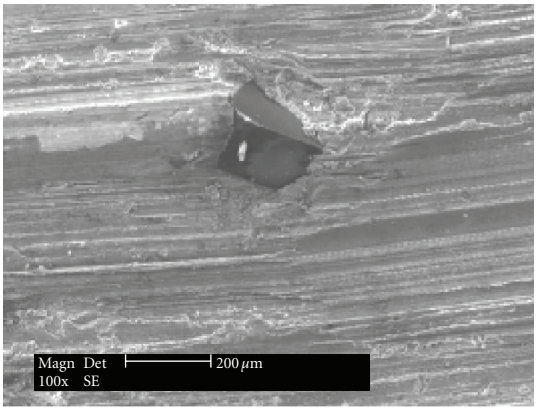


(a) no-added CeO_2

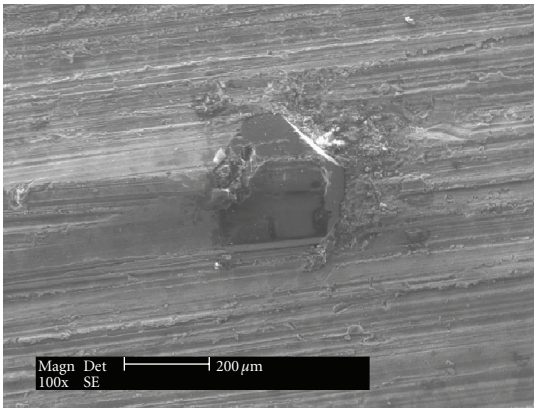


(b) added CeO_2 (0.05%wt)

Figure 7: SEM photograph of samples fracture.



(a) no-added CeO_2



(b) added CeO_2

Figure 8: The out-edge height of diamond.

Figure 6 shows X-ray analysis result. There are Al_2O_3 and Ce in CeO_2/Fe matrix composite, which explains that the reaction between CeO_2 and aluminum is capable of occurring, that reaction is shown in formula (3).

For workout, the more CeO_2 (0.5%wt) is added to CeO_2/Fe matrix composite, so there is CeO_2 in Figure 6.

3.5. Fabrication and Properties Analysis of CeO_2/Fe Matrix Composite. Figure 7 is SEM photograph of samples fracture on CeO_2/Fe matrix composites. Figures 7(a) and 7(b) show that there are more dimples in added CeO_2 Fe matrix composite than in no-added CeO_2 one, which shows that CeO_2/Fe matrix composite has higher toughness than Fe matrix composite. It is perhaps because CeO_2 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-CeO_2/Fe Matrix Composite on Diamond Saw Blade

Figure 8 is the out-edge height of diamond. Applying nano-CeO_2 to Fe matrix diamond saw blades, the result obtained from Figure 8 shows that the out-edge height of diamond added nano-CeO_2 is higher than that of no-adding nano-CeO_2 in edges of diamond saw blade. And so the diamond saw blade added nano-CeO_2 is sharper.

Table 1: The characteristics of different diamond saw blades.

Kind of diamond saw blades	Holding strength (MPa)	Cutting speed (m/minute)	Cuting life (m)
No-added nano-CeO_2	566	30.5	3450
Added nano-CeO_2	624	39.8	3475

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-CeO_2 is 58 MPa higher than that for no-adding nano-CeO_2. So under the same condition of cutting life, added nano-CeO_2 diamond saw blade is clearly sharper than the no-adding nano-CeO_2 one.

5. Conclusions

(1) The investigation used agglomerating method to prepare CeO_2 nanopowder. Preparation principium of CeO_2 nanopowder is as follows:

$$3(NH_4)_2CO_3 \cdot H_2O + 2Ce(NO_3)_3 \cdot 6H_2O = Ce_2(CO_3)_3 \cdot 8H_2O \downarrow + 6NH_4NO_3 + 7H_2O \quad (4)$$

In the dryness process at 300°C for 1 hour, the reaction creates CeO_2 nanopowder as follows:

$$2Ce_2(CO_3)_3 + O_2 = 4CeO_2 + 6CO_2 \uparrow \quad (5)$$

CeO_2 nanopowder is of batt shape, whose size is about 20 nm.

(2) In the sintering process at 800°C for 5 minutes, CeO_2 in the matrix is deoxidized by aluminium which creates active [Ce]. The reaction is as follows:

$$3CeO_2 + 4Al \longrightarrow 2Al_2O_3 + 3[Ce] \quad (6)$$

to produce active [Ce] and nano-Al_2O_3.

(3) Applied nano-CeO_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_2.

Acknowledgments

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