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Effect of La_2O_3 content on wear resistance of alumina ceramics

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Abstract: In order to improve the wear resistance, a kind of alumina ceramic with good wear resistance was created in an Al_2O_3-$CaCO_3$-SiO_2-MgO-La_2O_3 (ACSML) system. The effects of La_2O_3 content on sintering temperature, bulk density, and wear rate were investigated. The wear rate of sample was as low as 0.0393‰. The wear resistance of the sample containing La_2O_3 has improved 43% than that of the sample without La_2O_3. Appropriate La_2O_3 doping could inhibit grain growth, enhance density, and purify grain boundary. La_2O_3 could diffuse into Al_2O_3 to form a solid solution and react with Al_2O_3 to form high-aluminum low-lanthanum complex oxides. The combination among Al_2O_3, the solid solution layer, and the layer of high-aluminum low-lanthanum complex oxides combined closely, which could improve grain boundary cohesion. Besides, the homogeneous distributions of elements made uniform structure. Finally, the wear resistance of alumina ceramic was improved.

Keywords: alumina ceramic; abrasive media; lanthanum oxide; wear resistance; rare earths

Ball milling is a critical unit process in many industries. The quality of abrasive media directly affects the quality of products. Therefore, it is very important to select the right material for milling.

Alumina ceramics are attractive for many industrial applications due to their excellent properties, such as high wear resistance, and the relatively low cost of manufacture[1]. So they are used as one kind of abrasive media material.

The demand for high purity alumina ceramic is increasing with the rapid development of industrial technology. The impurity content is the key issue in preparing high purity alumina ceramics. However, abrasive media is one of the main pollution sources. So it is very important to prepare high-alumina abrasive media with good wear resistance. In the current market, the content of alumina is generally less than 95% in high-alumina abrasive media. There are hardly abrasive media containing more than 95% alumina with good wear resistance. In general, processing and manufacturing of pure alumina products are a difficult and expensive task. Therefore, additional compounds are added to alumina to minimize the product processing and manufacturing costs[2].

The application of rare earth elements in ceramic industry has made a satisfactory progress in recent years[3–8]. However, few investigations on the effect of rear earth on the wear resistance have been reported.

In the present study, we focused on the effect of La_2O_3 content on the wear resistance of alumina ceramic in an ACSML system. Through the design of formula and control of the preparation process, an alumina ceramic with good wear resistance was gained. The sintering temperature, wear rate, phases, and microstructure were investigated. Furthermore, two extra experiments, solid solution of La^{3+} in $CaAl_{12}O_{19}$ and a high temperature reaction model of La_2O_3 with single-crystal alumina were done so as to provide strong evidences for the wear resistance mechanism.

1 Materials and methods

Samples were prepared using a commercial, mono-sized α-Al_2O_3 powder (>99.8% purity and a mean particle size of 0.65 μm). The powder was mixed with magnesia, calcium carbonate, silicon dioxide and lanthanum oxide. The sum of Al_2O_3 and La_2O_3 was 98 wt.%. When the contents of lanthanum oxide were 0, 0.2 wt.%, 0.8 wt.%, 1.6 wt.% and 2.4 wt.%, the samples were referred to as L_0, L_2, L_8, L_{16}, and L_{24}. The powders were mixed and ball milled for 24 h in a water medium. Then, the slurry was dried in an oven. The dried powders were subsequently crushed to remove soft agglomerates that resulted from the drying procedure. Next, the powders were pressed at 100 MPa by a cold isostatic pressing (CIP). Samples were shaped into sphere of 30 mm in

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diameter and sintered in a box-type electrical resistance furnace at 5 ºC/min up to a right temperature for 1 h in air. After those processes, bulk density and wear rate were tested.

Bulk density was measured to an accuracy of 0.01 g/cm^3 by the Archimedes method with deionized water as the immersion medium. The wear rate testing process was as follows for each sample: weighed sample (M_1) and measured diameter (D_x). Then put the sample into a polyurethane pot (inner diameter: 200 mm; length: 220 mm) and mill for 24 h in water medium. Dry the sample and weigh it again (M_2). The wear rate is calculated by the following equation: $W=KD(M_1–M_2)/M_1$, where W is wear rate (‰), K a constant (4.17×10^{-4} mm^{-1}), D the mean diameter (mm) of samples, M_1 the mass before wear (g), and M_2 the mass after wear (g).

Solid solution experiment: $La_{0.3}Ca_{0.7}Al_{12}O_{19.15}$ and $CaAl_{12}O_{19}$ were synthesized for study. The sintering temperature is 1600 ºC for 3 h in air. High temperature reaction model experiment: put La_2O_3 powder to coat on single-crystal alumina. And then, they were sintered at 1600 ºC for 3 h.

X-ray powder diffraction (XRD) and field emission scanning electron microscopy (FESEM) were used to analyze the samples. The XRD tests were carried out in an X'Pert PRO multi-purpose X-ray diffractometer (PANalytical B.V., Almelo, Netherlands). It was used to analyze the phase composition. Samples were polished and coated with gold, and analyzed by a field emission scanning electron microscope (FESEM; S-4800, Hitachi, Japan) with energy dispersive spectroscopy (EDS).

2 Results

2.1 Effect of La_2O_3 content on sintering temperature

The sintering temperature of samples increase with the increasing of La_2O_3 content (Fig. 1). Water absorption of sample was measured as a function of sintering temperature. The sintering temperature was determined by water absorption being 0%.

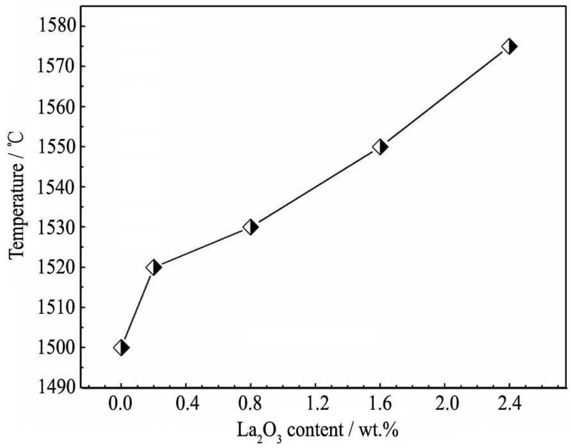

Fig. 1 Sintering temperature curve of samples

The sintering temperature of sample L_0 without La_2O_3 was 1500 ºC. When 0.2 wt.% La_2O_3 was added to the raw materials (Sample L_2), the sintering temperature was 1520 ºC. When the La_2O_3 content was added from 0.2 wt.% to 2.4 wt.%, the sintering temperatures increased from 1520 to 1575 ºC. Adding La_2O_3 to alumina can raise sintering temperature.

The melting point of La_2O_3 (2217 ºC) is higher than that of Al_2O_3 (2000–2050 ºC). Add high melting substances to the raw materials and there is no eutectic point in the ingredient range, which will lead to the increase of sintering temperature. Additionally, the large rare-earth ions can block the migration of particles, thus affecting the sintering of ceramic.

2.2 Effect of La_2O_3 content on bulk density and wear rate

The wear rates and bulk densities of La_2O_3-free and La_2O_3-added samples were measured. The results are presented in Fig. 2.

It can be seen that the wear rates of samples vary parabolically with the increase of La_2O_3 content. The wear rate of sample L_0 without La_2O_3 is 0.070‰. When the La_2O_3 content is 0.2 wt.%, the wear rate declines to 0.058‰. The wear rates of samples still decrease with the increasing of La_2O_3 content. When the La_2O_3 content is 1.6 wt.%, the wear rate is as low as 0.039‰ and the bulk density is 3.90 g/cm^3. The wear rate of sample L_{16} is the lowest, and the bulk density is the maximum. It is reported that the addition of La_2O_3 is helpful to promote densification[9–12]. However, when the La_2O_3 content is 2.4 wt.%, the bulk density and wear rate are worse than sample L_{16}. The chart shows an upward trend in wear rate and a downward trend in bulk density when the La_2O_3 content exceeds 1.6 wt.%. But the densities of La_2O_3-doped samples are higher than that of La_2O_3-free sample; and the wear rates of La_2O_3-doped samples are lower than that of La_2O_3-free sample. Under the equivalent conditions, the wear rate of a product with good resistance on the market is 0.172‰. The wear resistance of sample L_{16} is enhanced about 77% over the product.

The experimental results indicate that La_2O_3 additive

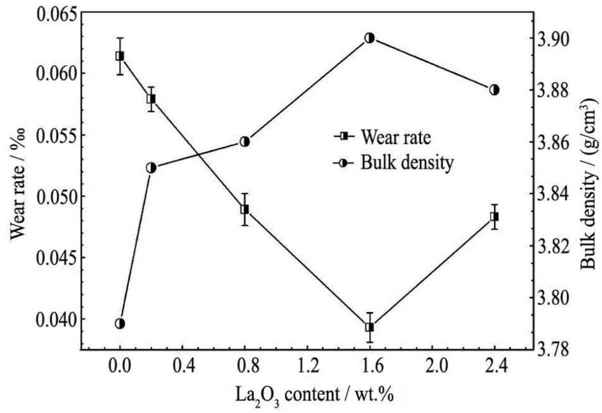

Fig. 2 Wear rate and bulk density curves of samples