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Effect of the grain size on the wear resistance of Al_2O_3 dispersed Y-TZP ceramics

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Using a block-on-ring tribometer with the revolving motion of high chromium cast iron (HCCI) ring against Al_2O_3 dispersed Y-TZP ceramics (ADZ) blocks, the wear resistance of ADZ ceramics with different grain sizes of ZrO_2 was investigated at room temperature. The results show that there was no direct relation found between the grain size and the wear resistance of ADZ ceramics. The tetragonal (t) monoclinic (m) martensitic transformation occurred during the friction process. Only for suitably sized t-ZrO_2 particles, the tm martensitic transformation occurred under the action of the frictional stress, and the phase transformation is beneficial for the wear resistance of ADZ ceramics. When the grain size of t-ZrO_2 particles is too small, no phase transformation toughening occurred. Moreover, many microcracks will be created by the phase transformation if the grain size is big enough. Then, these microcracks lead to fracture and have a negative effect on the wear resistance of ADZ ceramics.

Key words: Y-TZP/Al_2O_3 ceramics, grain size, wear resistance.

Introduction

Y-TZP ceramics have become more commercially important as engineering materials due to their high mechanical properties, especially their excellent wear resistance. Concerning the friction and wear properties of zirconia ceramics, a variety of factors have been investigated, mainly including external factors and internal factors. The former [1-3] includes sliding speed, load, sliding distance, lubricant, etc. Whilst the latter are the mechanical properties and microstructure of materials such as the hardness, fracture toughness [4-5], the second phase, grain size and shape, pore voids, grain boundaries, etc. X. P. Liang *et al*. researched the effect of the alumina phase on the wear resistance [6]. The porosity and texture formation [7] was also studied by Akimov, et al. For the grain size, pioneering works by He *et al*. [8] showed that the critical load of the wear mechanism transformation was in direct correlation with the grain size. Simultaneously, Zum Gahr *et al* [9] indicated a Hall-Petch type of relationship between wear the resistance and grain size, which is $W^{-1} \propto G^{-n}$, and the power factor (n) may be 2 or another value. Moreover, in the research of Yingjie *et al*. [10], for a grain size < or = 0.7 μm, the relationship should be $W^{-1} \propto G^{-1/2}$, and for grain sizes > or = 0.9 μm, the wear resistance was proportional to the reciprocal of the grain diameter. Generally, it is usual that the wear resistance was in inverse proportion to the grain size for a TZP. However, less attention has been paid to the effect of the tetragonal (t) monoclinic (m) martensitic transformation on the relationship of the wear resistance to the grain size. And the results may be more reasonable if the critical transformation size and transformation toughening are considered.

Accordingly, the aim of this investigation is to study the effect of the grain size of ZrO_2 particles on the wear resistance of Al_2O_3 dispersed Y-TZP ceramics (ADZ ceramics). The sliding tests were performed on a block-on-ring tribometer, and the microstructural evolution during the friction process and the wear mechanisms are discussed.

Experimental

Preparation

ADZ ceramics was prepared using 20 wt% high-purity α-Al_2O_3 powder and commercially available, co-precipitated ZrO_2-3 mol% Y_2O_3 powder as raw materials. The mixed powders were molded through dry pressing and isostatic pressing, and sintered at 1470 °C, 1510 °C and 1550 °C for 2 hours (named ADZ-1, ADZ-2and ADZ-3). Then, these sintered samples were polished to achieve about 0.03-0.08 μm R_α of the surface roughness. Lastly, the specimens were ultrasonic cleaned with anhydrous alcohol for 25 minutes and dried at 85 °C for an hour.

Experimental measurements and characterization

The tribological experiments were performed on an M-200 ring-block wear testing machine under 5 wt% NaOH aqueous solution with 2 wt% SiO_2 abrasive particles. Also

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the counterpart high chromium cast iron ring, whose inner bore was 16 mm and external diameter 40 mm, was sliding at 0.42 m/s for 30 minutes under a load of 100N-500 N. The wear rate was calculated by measuring the volume loss. The transformation of samples before and after wearing was characterized by a D8 DISCOVER X-ray diffractometer (XRD). Also the surfaces were analyzed by an S-500 scanning electron microscope (SEM).

Results and Discussion

The average grain size

The SEM micrographs of ADZ ceramics at different sintering temperatures are shown as Fig. 1. The evidence is that the grain size of ZrO_2 grows with an increase of the sintering temperature, and the average grain sizes of ADZ-1, ADZ-2 and ADZ-3 were 0.1 μm, 0.25 μm and 0.45 μm, respectively.

The wear rate

Fig. 2 shows the wear rate of ADZ samples under loads of 100 N, 300 N and 500 N. This clearly indicates that grain size has an effect on the wear resistance of ADZ ceramics. However different from the conventional result [9, 10], the wear rate of Y-TZP matrix ceramic materials does not increase monotonically with grain size. That is, ADZ-1 with an 0.1 μm grain size did not have the lowest wear rates under the three different loads, but rather the ADZ-2 sample with an average grain size of 0.25 μm.

Surface Structures

Fig. 3 shows the relationship between the average grain size and the m-ZrO_2 content on the surface before and after wearing. In ADZ-1, the t-ZrO_2 grains are very stable and hardly susceptible to transformation. So no monoclinic phase was found. While, in ADZ-2 and ADZ-3, the tm martensitic transformation occurred. The m-ZrO_2 content in ADZ-2 gave a small growth (7%) during the friction process. Also the m-ZrO_2 content of ADZ-3 was increased from 6.8% and reached 19.8%. It is clear that an increase of grain size will result in a relatively larger tm martensitic transformation of ZrO_2 under the action of a frictional stress.

Wear Mechanisms

As discussed above, the grain size has an effect on the tm martensitic transformation of ZrO_2, and then an effect on the wear rate of ADZ ceramics. Also there was no direct correlation found between the grain size and the wear resistance of ADZ ceramic materials. Meanwhile, the wear resistance of the TZP was not simply inversely

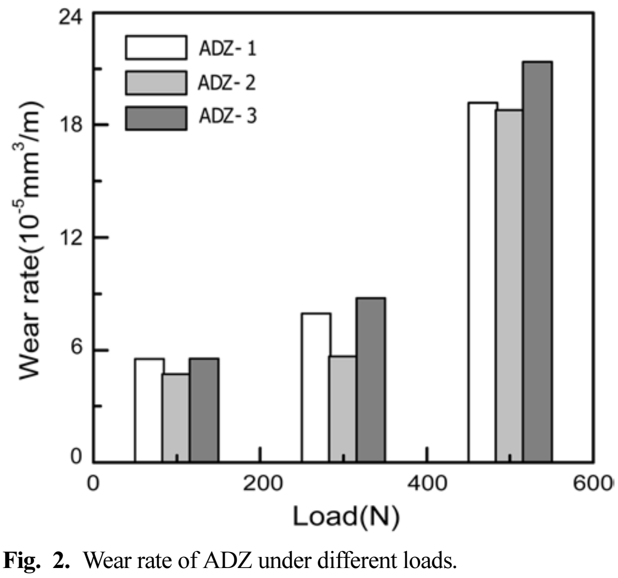


Fig. 2. Wear rate of ADZ under different loads.

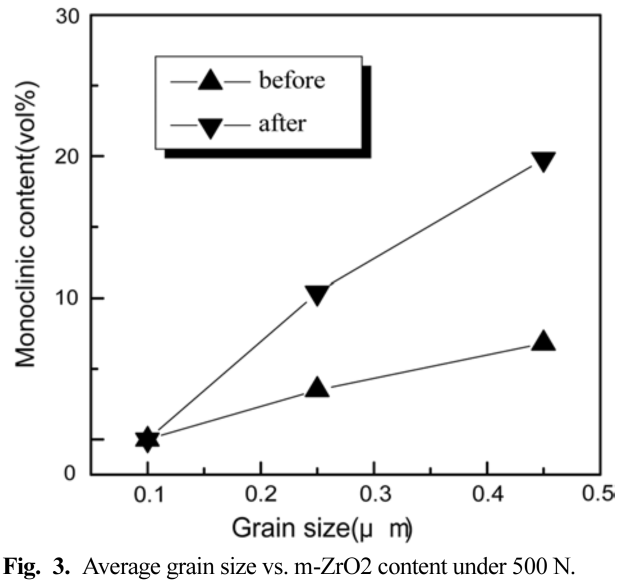
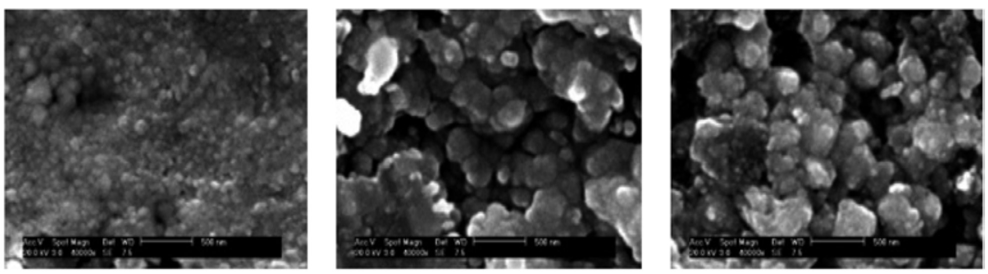
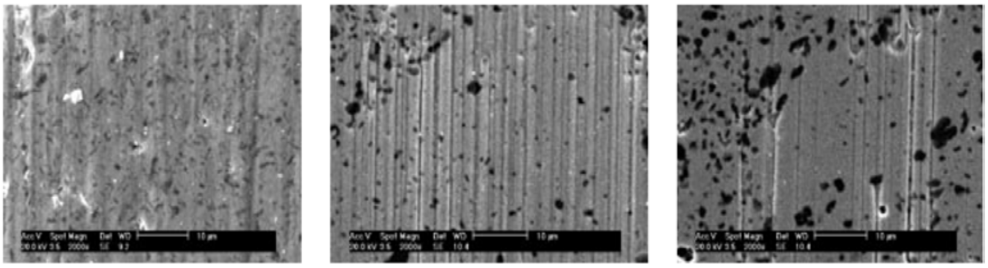


Fig. 3. Average grain size vs. m-ZrO2 content under 500 N.



(a) ADZ-1, at 1470℃ (b) ADZ-2, at 1510℃ (c) ADZ-3, at 1550℃

Fig. 1. SEM micrographs of ADZ ceramics sintered at different temperatures.



(a) ADZ-1 (b) ADZ-2 (c) ADZ-3

Fig. 4. SEM micrographs of ADZ ceramics worn surfacea under a 500N load.

proportional to the ZrO_2 grain size, and a critical transformation size should be considered.

Fig. 4 shows the SEM micrographs of ADZ ceramics worn surfaces with different grain size under a 500 N load. Inspection of all wear tracks of the ADZ-1 and ADZ-2 ceramics showed that the surfaces were relatively smooth and continuous, and this is due to the plastic deformation. For ADZ-1, a low wear rate was obtained, and the main reason is that the particles are fine enough. Literature data [11] shows that the critical transformation size of ZrO_2 grains is in the range of 0.311-0.350 μm. Some ZrO_2 particles in ADZ-2 absorb the frictional energy and reach the critical size. Then a proper amount of the tm martensitic transformation occurred during the friction process, which can induce some microcrack on the ADZ-2 surface. This stress-induced phase transformation toughening and the microcrack toughening can increase the fracture toughness. So ADZ-2 showed the best wear resistance.

In contrast, for ADZ-3, shown as the Fig.4(c), shear facture followed by spalling or fragmentation of grains was evident, and the fracture track and a concave pit after grain pull out prevailed on the worn surface. This may be explained by the fact that a grain size of 0.45 μm means an uncompleted transformation of the t-ZrO_2. The effects of frictional heat and the shear stresses induced the grain growth of the remaining tetragonal particles so that some t-ZrO_2 reached its critical size, and 13% tm martensitic transformation occurred. The relatively large number of grains undergoing a martensitic transformation associated the volume expansion will weaken the grain boundary strength and the binding force of t/m grain interfaces. Also this caused pulling-out of the grains and many microfractures under the high shear stress during the friction processes, which lead to an increase of the wear rate of ADZ-3. The main deterioration mechanisms are brittle fracture and grain pull out.

Conclusions

The study demonstrated a variable influence of the grain size on the wear resistance of Al_2O_3 dispersed Y-TZP ceramics. The most useful result found was that the wear rate of ADZ ceramics is not monotonically increased with the ZrO_2 grain size. There is a critical grain size for the t-ZrO_2 phase transformation which should be considered. For suitably sized t-ZrO_2 particles, the tetragonal (t) monoclinic (m) martensitic transformation occurred under the action of the frictional stress and this phase transformation is beneficial for the wear resistance of the TZP ceramics. When the grain size of t-ZrO_2 particles is too small, no phase transformation toughening occurred. Moreover, many microcracks will be created by the phase transformation if the grain size is large enough. Then, these microcracks lead to fracture whuch had a negative effect on the wear resistance of the ADZ ceramics.

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