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A Study on the Wear Resistance of ZrO_2/Al_2O_3 Ceramic Scissors for Spinning and Weaving

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A new kind of zirconia matrix ceramic material (ZrO_2/Al_2O_3) has been developed with 3Y-PSZ (3 mol% Y_2O_3 partially stabilized ZrO_2) and the additive of alumina. The wear resistance of ZYA20 (3Y-PSZ+20 wt.%Al_2O_3) has been experimentally investigated compared with ZYA30 (3Y-PSZ+30 wt.%Al_2O_3) by the wear ring-block test. It is shown that the friction coefficients of ZYA20 and ZYA30 decrease with the increment of the applied load and the wear ratios increase with the increment of the applied load. It is also found that their wear mechanisms are plastic deformation, adhesive and abrasive wear, as well as stripping. The wear resistance of ZYA20 and ZYA30 are very good at low load and ZYA20 is stronger than ZYA30.

Keywords composite ceramics, spinning and weaving scissors, wear resistance

1. Introduction

With the rapid development of the spinning and weaving industry, the requirement for high performance scissors for spinning and weaving is becoming urgent. In China, most of the ceramic scissors for spinning and weaving are imported, which requires a large amount of foreign currency. So far, many researchers have investigated the zirconia (Zr) matrix ceramics such as 3Y-TZP(3 mol% Y_2O_3 + Tetragonal Zirconia Polycrystal) and 3Y-PSZ(3 mol% Y_2O_3 + Partially Stabilized Zirconia) and their wear resistance and mechanisms by experiments.[1-3] But their wear resistance is far from the practical requirement.

To develop new ceramic scissors for spinning and weaving, two kinds of ceramics (ZYA20 and ZYA30) have been fabricated using Zr as the matrix and alumina as the additive. Their wear resistance and mechanisms have been studied and discussed systematically.

2. Experiment

2.1 The Fabrication of ZrO_2/Al_2O_3 Ceramics

The 3 mol% Y_2O_3 partially stabilized ZrO_2 (3Y-PSZ) with a grain size of 5 μm is used as the matrix material, the α-Al_2O_3 powder with a grain size of 6 μm is used as the second dispersed phase, and a little amount of CaO and MgO are added to the ceramic composite as additives. The material nominal compositions are shown in Table 1. The mixed powders containing CaO, MgO, Al_2O_3, and ZrO_2 (3Y-PSZ) were milled for several hours in ethanol with high-purity alumina balls. All composites were hot-pressed at 1500-1600 °C for 1 h in a graphite die with 30 MPa applied pressure. The mechanical properties of different composition proportion composites were obtained under various hot applied technologies.

The flexural strength, hardness, and fracture toughness of the new ceramics were tested and the wear resistance was assessed by the ring-block wear test, which will be presented later in the paper. The flexural strength was measured in static air using 3 × 4 × 30 mm polished test bars under three-point bending with a span of 30 mm and a loading rate of 0.5 mm/min with an electronic universal test machine WD-10 (Jinan Tester Group, Jinan, Shandong, China). The test specimens were made using the same materials and fabrication process as the ceramic scissors for spinning and weaving.

The fracture toughness was measured with an indentation method. The indenter is the Vickers DPH (Diamond Pyramid Hardness) type and the applied static load is 196 N. In measuring the fracture toughness, 10 samples were used, 10 indentations were made on each sample, and four crack lengths were obtained from each indentation. For each test, the fracture toughness value was evaluated by using Eq 1 found in Ref. 4:

$$K_{IC} = 1.99 \cdot \left(\frac{c}{a}\right)^{-1.5} \cdot \left(\frac{a}{1000}\right)^{0.5} \cdot HV \qquad \text{(Eq 1)}$$

where K_{IC} is the fracture toughness ($MPa \cdot m^{0.5}$), a is a half of the indentation diagonal length (mm), c is a half of the crack length (mm), and HV is the Vickers hardness (N/mm^2). Thus, a total of 400 fracture toughness values for each ceramic were obtained and the average was taken as the final fracture toughness value.

The hardness was measured with the Vickers hardness test. The diamond indenter was used with a total load of 196 N. The hardness for each composite was the average of the 10 samples with eight indentations on each sample. The mechanical properties of the developed ceramics are shown in Table 2.

2.2 The Wear Experiment

2.2.1 The Wear Experiment. The wear resistance experiment was carried out on the friction-wear test machine

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MM-200 (Jinan Tester Group). The ring-block friction without coolant was used in the experiment. The material of the ring was a kind of cemented carbide (K20) with a surface roughness of Ra 0.08 μm and the hardness of 89 HRA. The experimental setup is shown in Fig. 1. The tested specimen of the ceramics was a cuboid with the size 30 × 10 × 10 mm and its surface roughness was Ra 0.1 μm in the wear experiment.

The wear volume of the two kinds of specimens (ZYA20 and ZYA30) and the moment of the friction force were measured with the rotating speed of the carbide ring being 200 r/min and with different applied load on the specimens (50 N, 100 N, 150 N, 200 N).

2.2.2 Measurement of the Friction Coefficient. The friction coefficient k is an important measure for the material friction characteristics, which is correlated to the moment of the friction force, the applied load on the specimen, and the diameter of the wear ring. The friction coefficient may be obtained by the following equation.

Table 1 The Nominal Compositions of Ceramics

No.	Al_2O_3, wt.%	3Y-PSZ, wt.%	CaO, wt.%	MgO, wt.%
ZYA20	20	79	0.5	0.5
ZYA30	30	69	0.5	0.5

Note. Compositions supplied by Beijing Steel and Iron Research Institute, Beijing, China.

Table 2 The Mechanical Properties of Ceramics

No.	Flexural Strength σ_{bb}, MPa	Hardness *HV*, GPa	Fracture Toughness K_{IC}, MPa · $m^{0.5}$
ZYA20	830 ± 50	17.6	8.5
ZYA30	530 ± 50	18.5	6.7

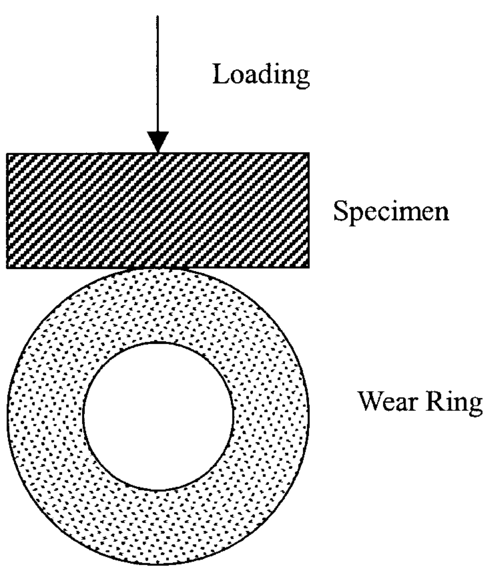


Fig. 1 The ring-block friction experimental setup (wear ring supplied by Zhuzhou Carbide Tool Factory, Zhuzhou, Hunan, China)

$$k = \frac{F}{P} = \frac{M}{P \times r} \quad \text{(Eq 2)}$$

where F is the friction force (N), P is the applied load on the specimen (N), M is the moment of the friction force (N · mm), and r is the radius of the carbide ring (mm).

2.2.3 Measurement of the Wear Ratio. The wear ratio of the material is the ratio of the wear volume to the moment of the friction force (m^3/N · m). The assumed wear trace of the specimen is shown in Fig. 2. It was easily found from Fig. 2 that the wear volume of the specimen could be calculated with the following relationship.

$$V = b\left[r^2 \sin^{-1}\left(\frac{l}{2r}\right) - \frac{l}{2}\sqrt{r^2 - \left(\frac{l}{2}\right)^2}\right] \quad \text{(Eq 3)}$$

where V is the wear volume of the specimen (mm^3), b is the width of the specimen (mm), r is the radius of the carbide ring (mm), and l is the span of the wear trace (mm).

3. Results and Discussion

3.1 Results

The relation between the friction coefficients or the wear ratio of the ceramics (ZYA20 and ZYA30) and the applied loads on the specimen are presented in Fig. 3 and 4, respectively.

It was found from Fig. 3 that the friction coefficients of ZYA20 and ZYA30 decreased gradually with the increment of the applied load on the specimens during the dry sliding process. Also, reducing the ratio of the friction coefficient for ceramics ZYA20 was higher than that for ceramics ZYA30 due to the higher plastic deformation of ZYA20 caused by its lower hardness and higher fracture toughness compared with ZYA30.

Figure 4 also showed that the wear ratios of ZYA20 and ZYA30 increased gradually with the increment of the applied load on the specimens during the dry sliding process. The increasing ratio of the wear ratio for ceramics ZYA30 was higher than that for ceramics ZYA20. But the wear ratios of ZYA20 and ZYA30 increased rapidly as the applied load reached 150 N.

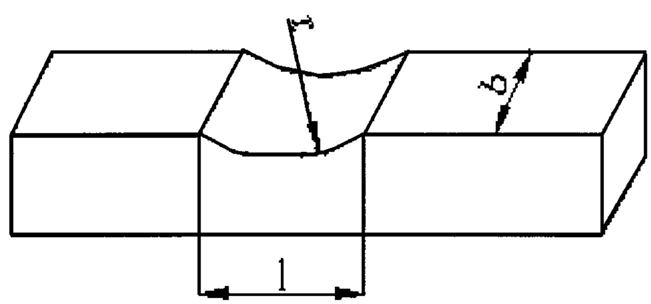


Fig. 2 The wear trace of the specimen

3.2 Wear Mechanisms

3.2.1 Wear Mechanisms at the Lower Applied Load (≤100 N). At the beginning of the sliding process at the lower applied load, the wear ring only slid on the surface protruding points of the tested ceramic materials. As such, the friction coefficients of ZYA20 and ZYA30 were higher at this sliding stage, which was in agreement with the experimental results in Fig. 3. Due to the lower actual sliding area, the stress at the protruding point was greater. When the stress exceeded the compressive strength of the tested material, plastic deformation was generated in the ceramics. With the development of the sliding process, the ground chips caused by the plastic deformation from the wear ring and from the tested ceramics adhered to the surface of both the wear ring and the tested ceramics, as the surface activity of the chips was higher. It could be easily seen from Fig. 5(a) that there was adhesive or plastic deformation wear along the sliding direction and vaguely had the characteristics of the abrasive wear caused by the hardened grains in the chips.

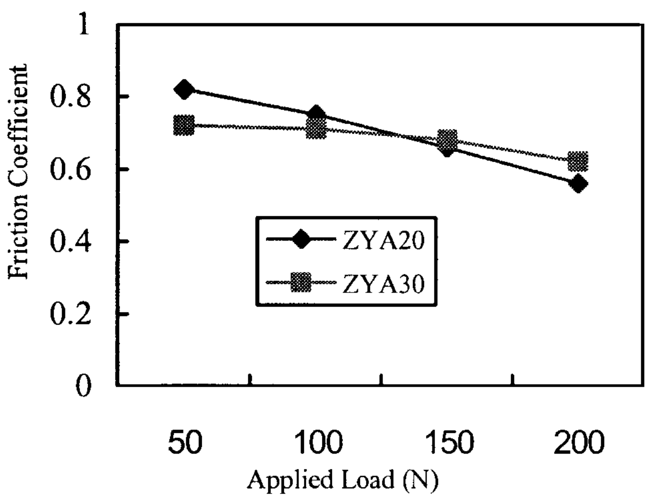


Fig. 3 The friction coefficient vs the load

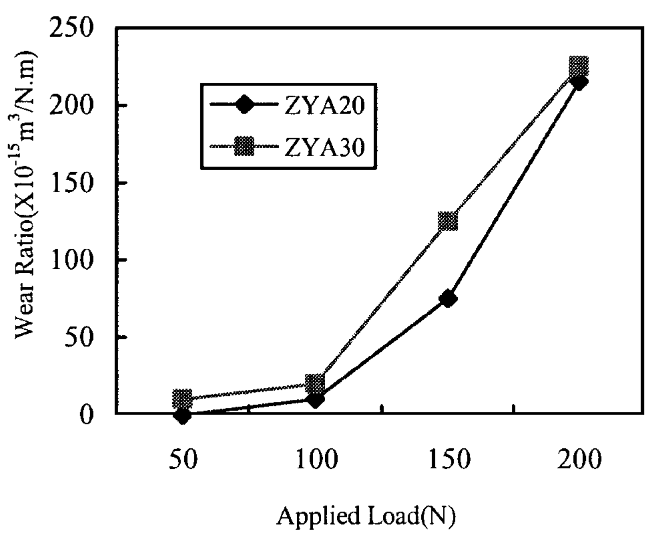


Fig. 4 The wear ratio vs the load

During the sliding process, the cracks along the sliding direction were generated by the large shear stress, which was formed in the adhesive layer on the tested ceramic surface. When the cracks continued to propagate and failed, the adhesive layer peeled off the tested material surface. The pattern of the crack propagation is shown in Fig. 5(b).

In conclusion, the wear mechanisms of ZYA20 and ZYA30 at the lower applied load are plastic deformation and adhesive wear.

3.2.2 Wear Mechanisms at the Higher Applied Load (≥ 100 N). The actual sliding area between the wear ring and the specimen increased with the enhancing of the applied load on the specimen. Thus, the higher sliding temperature intensified the plastic deformation of the sliding zone on the specimen, which further caused more ground chips. The ground chips adhered firmly to the ceramics' surface and formed the large area of adhesive layer, which resulted in reduction of the friction force. As such, the friction coefficient decreased with the increment of the applied load, which was in agreement with the experimental results shown in Fig. 3. It can be seen from Fig. 6(a) that the adhesive layer at the higher applied load was thicker than that at the lower applied load shown in Fig. 5(a). It demonstrated experimentally that the plastic deformation at the higher applied load was heavier than that at the lower applied load on the sliding surface.

As shown in Fig. 6(b), the microcracks on the sliding surface that propagated parallel or perpendicular to the sliding direction resulted in the stripping and wear of the tested ceramics.

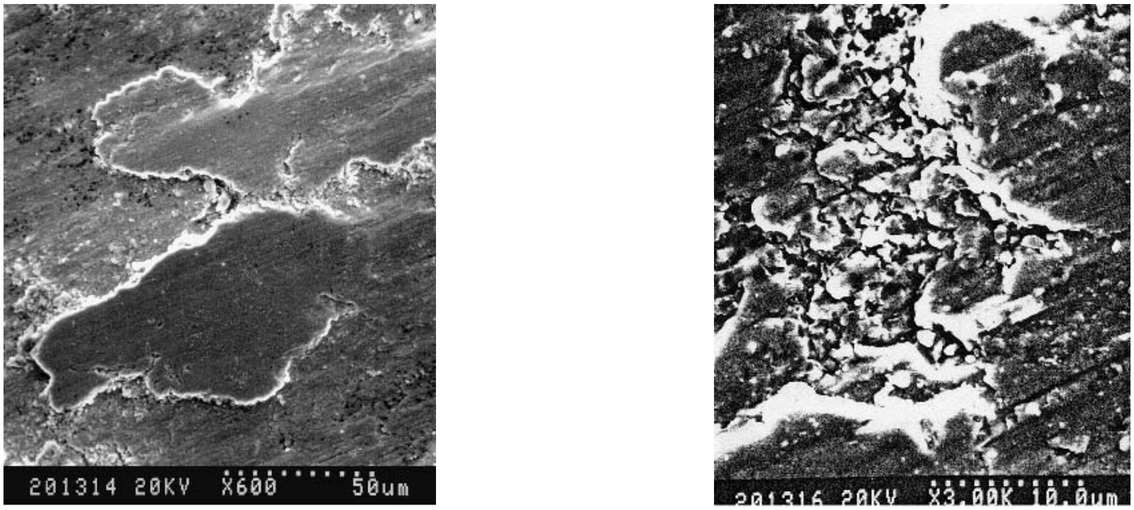
As the fracture toughness of ZYA20 was higher than that of ZYA30, crack generation in the ZYA20 was more difficult than in the ZYA30. Thus, the wear resistance ability of ZYA20 was stronger than that of ZYA30. On the other hand, because more ground chips were generated from ZYA30 than from ZYA20 and caused the sliding surface of ZYA30 to be rougher, the friction coefficient of ZYA30 was higher than that of ZYA20 at the applied load of 150-200 N shown in Fig. 3. This research result was in agreement with that of previous research.[5] Simultaneously, slight abrasive wear on the ceramics ZYA20 and ZYA30 was caused by the hardened alumina.

It is concluded from the above analysis that the wear mechanisms of ZYA20 and ZYA30 are plastic deformation, peeling and abrasive wear.

It was experimentally proven that the two types of ceramics (ZYA20 and ZYA30) could be used to make scissors for spinning and weaving, the research result of which was discussed in another paper.

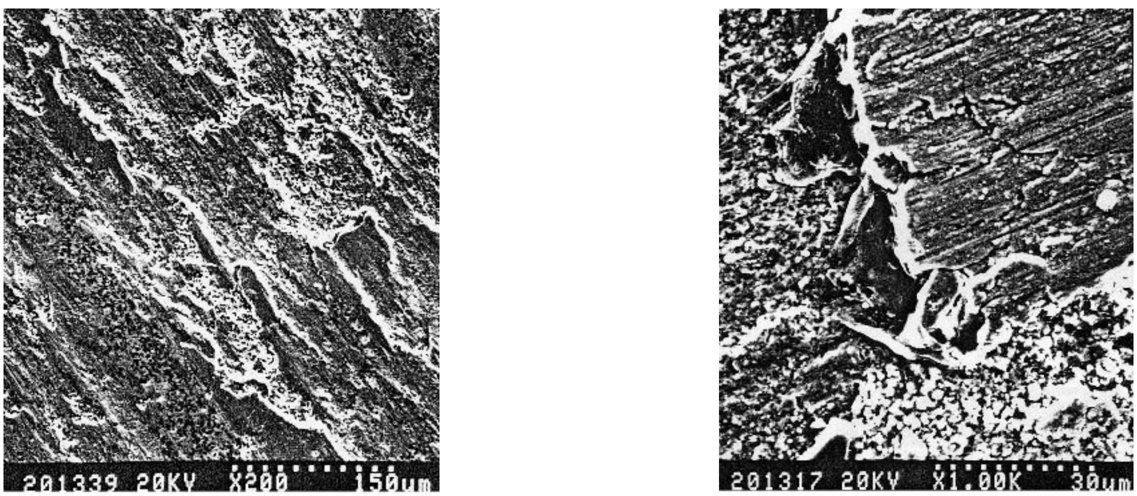
4. Conclusions

1) In the experimental conditions, the friction coefficients of ZYA20 and ZYA30 decreased with the increment of the applied load and the wear ratios increased with the increment of the applied load.
2) The wear resistance of ZYA20 was stronger than that of ZYA30, as the fracture toughness of ZYA20 was higher than that of ZYA30.



(a) (b)

Fig. 5 Scanning electronic microscope (SEM) morphology of the wear surface



(a) (b)

Fig. 6 SEM morphology of the wear surface at the load of 150 N

3) The main wear mechanisms of ZYA20 and ZYA30 were plastic deformation, stripping, and adhesive and abrasive wear.
4) It was proved experimentally that the two types of ceramics (ZYA20 and ZYA30) could be used to make scissors for spinning and weaving

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