Tribological properties of hot pressing alumina matrix ceramic materials improved by Zr-O-B compounds

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Abstract. $Al_2O_3/ZrB_2/ZrO_2$ composites were fabricated by hot pressing technology. The friction and wear behavior of this new material, coupled with cemented carbide ball in unlubricated conditions, were investigated. Experimental results showed that the friction coefficient values and wear rate of alumina matrix ceramic composites toughened by Zr-O-B compounds were lower than that of pure alumina. The generated lubricating film can decrease the friction coefficient of the composites, and makes the wear rate did not reach the theory value.

Introduction

Nowadays, composites made of advanced ceramics can survive and perform well at higher operating temperature, and improve the wear resistance. They are widely applied in the fields of high temperature measuring implement, cutting tools, working platform and high-speed bearing, etc., where high temperature durability and long working life are required. Among these advanced ceramics, alumina matrix ceramic materials are widely selected due to their virtues of high hardness, good chemical inertness, high wear resistance, low coefficient of thermal expansion and friction coefficient. However, the brittleness of pure Al_2O_3 limits its potential applications [1-5]. Cemented carbides have outstanding properties of high levels of hardness and wear resistance. The advent of cemented carbides began with the idea of replacing costly diamond wire drawing dies for tungsten filaments. After that, attention was drawn to better cutting tools and finally to a variety of wear parts and machine components [6-7].

The tribological behaviour of alumina has been the topic of many investigations during the last decades. The reason is not only owing to remarkable tribological characteristics of alumina, but also the behavior is greatly influenced by incorporating other elements, changing contact load and speed, temperature, counterface materials, environment, and so on [8-10]. Though many achievements made in tribology of alumina, it is noted that most of these studies were focused on the tribological behaviour of alumina sliding against ceramic or steel [11-12], and there are few articles reporting the tribological properties of alumina or reinforced alumina ceramic sliding against cemented carbides. The enormous cost of tribological deficiencies to any national economy is mostly caused by the large number of energy and material losses occurring simultaneously on virtually every mechanical device in operation. When reviewed on the basis of a single machine, the losses are small. However when the same loss is repeated on perhaps a million machines of a similar type, then the cost becomes very large [13].

In our previous investigations, the introduction of Zr-O-B compounds into alumina matrix can change the fracture mode [14]. However, few papers reported the tribological properties of Zr-O-B compounds reinforced alumina ceramic sliding against cemented carbides, which would be useful in special engineering contact, such as bearings and rails. From the above point of view, this study aims at the influences of sliding velocity and normal load values on the friction and wear behaviour of alumina reinforced with ZrB_2/ZrO_2 compounds sliding against cemented carbides are studied. In particular, the wear mechanisms and microstructure characteristics are discussed.

Experimental section

The employed raw materials were high purity Al_2O_3 powder having small grain size of about 500 nm. In the Zr-O-B compounds, the content of ZrB_2 is 92.2% ±0.1% by volume, the content of ZrO_2 is 7.8% ±0.1% by volume. The particle size of the compounds is about 0.5–1µm. The compositions and mechanical properties of the composite materials are shown in Table 1. The suffix in AZ0, AZ10, AZ20, AZ30 and AZ40 represented the volume content of Zr-O-B compounds. For example, AZ0 means the weight content of Zr-O-B compounds is zero.

Table 1 : Compositions and mechanical properties of the AZ series materials

Specimen	Compositions (vol. %)	Relative density (%)	Bending strength (MPa)	Hardness (GPa)	Fracture toughness (MPa $m^{1/2}$)
AZ0	100%Al_2O_3	$92.6^{+0.9}_{-1.3}$	$353.1^{+28.7}_{-30.2}$	$16.2^{+0.5}_{-0.4}$	$3.28^{+0.23}_{-0.28}$
AZ10	90%Al_2O_3+10% ZrB_2/ZrO_2	$96.4^{+1.6}_{-1.2}$	$621.7^{+36.9}_{-38.6}$	$24.0^{+0.8}_{-0.5}$	$5.11^{+0.32}_{-0.29}$
AZ20	80%Al_2O_3+20% ZrB_2/ZrO_2	$98.7^{+0.9}_{-0.8}$	$760.9^{+42.1}_{-38.2}$	$23.1^{+0.6}_{-0.6}$	$6.19^{+0.25}_{-0.37}$
AZ30	70%Al_2O_3+30% ZrB_2/ZrO_2	$93.6^{+1.4}_{-0.9}$	$615.4^{+45.9}_{-48.3}$	$19.5^{+0.4}_{-0.2}$	$5.14^{+0.28}_{-0.33}$
AZ40	60%Al_2O_3+40% ZrB_2/ZrO_2	$98.7^{+1.0}_{-0.6}$	$557.8^{+33.8}_{-35.5}$	$18.7^{+0.3}_{-0.6}$	$4.79^{+0.19}_{-0.26}$

Friction and wear tests were carried out in a ball-on-disc tribology tester (UMT Multi-Specimen Test System, Center for Tribology, Campbell CA 95008, USA). The contact schematic image for frictional couple is shown in Fig. 1.

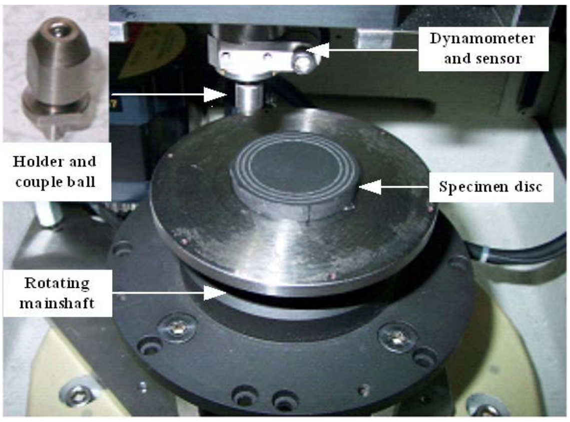


Fig. 1. UMT Multi-Specimen Test System (Center For Tribology, USA).

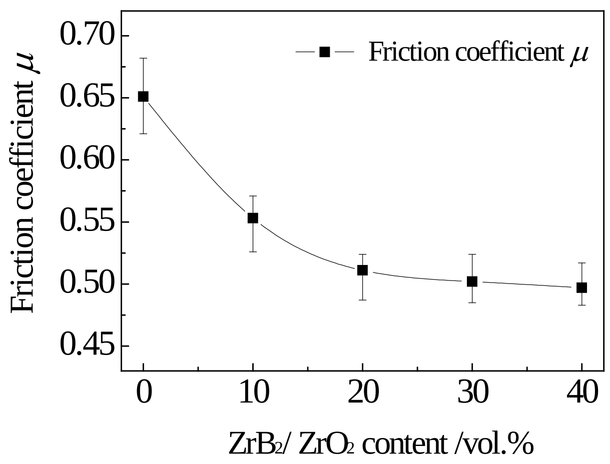
The diameter of couple ball was 4mm, and the material is WC cemented carbides. The specimen discs were grinded by vertical spindle grinder and polished with diamond paste to an average surface roughness of 50 nm. The dimension of the specimen disc was Ø42mm×6.5mm. Friction force could be directly attained from the test system. Friction coefficient was caclculated by tribology tester. A moving average was used to report the Friction coefficient, because the sensitivity of the sensor to both the normal and horizontal forces resulted in some scatters for the data. The white light interferometer (Wyko NT9300, Veeco Corporation, USA) is shown in Fig. 2, which can provide a fast, high-precision three-dimensional surface topography, and the precision can be reach to 0.1nm in the vertical scanning range for measurement function.

Fig. 2. White light interferometer (Wyko NT9300, Veeco, USA).

Results and discussion

After friction and wear tests, the measured friction coefficient of AZ0, AZ10, AZ20, AZ30 and AZ40 at the liner speed of 1.33m/s and normal load of 6N are shown in Figs. 4. It is evident that, the increasing of ZrB_2/ZrO_2 volume content can decrease the friction coefficient of AZ series composites. This phenomenon may be related to oxidation of ZrB_2 materials during the friction and wear tests. It has been investigated in our previous research that the composites began to oxidate at 500°C~700°C, and the oxidation of ZrB_2 follows the reaction: $ZrB_2+5/2O_2 \rightarrow ZrO_2+B_2O_3$[20]. The generated ZrO_2 and B_2O_3 can form a self-lubricating film, which could improve the tribological behavior and prevent the adhesive wear at high temperature. As a result, the higher ZrB_2/ZrO_2 compounds, the larger generated ZrO_2 and B_2O_3, and which may be contribute to decreasing the friction coefficient of AZ series composites.

Wear rates vs. ZrB_2/ZrO_2 volume content for AZ series composites when dry sliding against cemented carbides is plotted in Fig. 5. Addition of ZrB_2/ZrO_2 compounds promote the densification rate of the composites, decrease interspaces or cavities, enhance the hardness and fracture toughness, and thus lead to better wear resistance. It can be observed from Fig. 5 that the wear rate of AZ20 specimen is lower than that of AZ0 and AZ40. On the one hand, the value of wear rate mainly depends on the hardness of the composites. Higher hardness brings on lower wear rate and they are inverse ratio. The hardness of AZ0 is 15.3GPa, and AZ40 is 18.2GPa, they are lower than that of AZ20 with 23.1GPa. So the wear rate increase as the hardness of composites decreases. On the other hand, when the content of ZrB_2/ZrO_2 is less than 20%, the ZrO_2 can play an active role in toughening the matrix by phase transformation technology. But, with the increase of ZrB_2/ZrO_2 ratio, more ZrB_2 will oxidize in this condition. A lot of ZrO_2 and B_2O_3 are in-situ generated, the hardness of the oxidation composites will dramatically decrease as the hardness of ZrO_2 itself is about 13GPa. So, AZ20 composite express the better wear resistance in the AZ series materials.



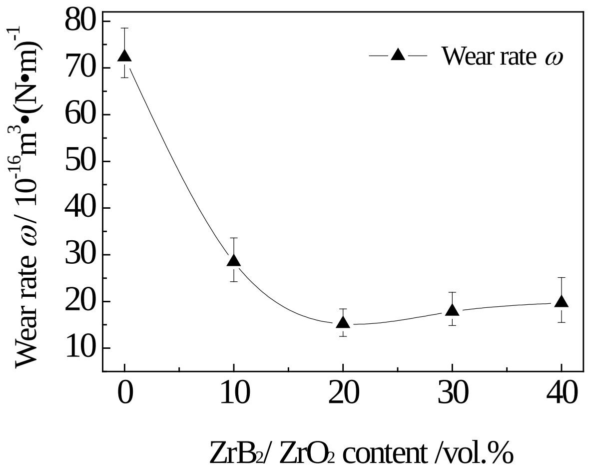


Fig. 5. Relation of ZrB_2/ZrO_2 content and friction coefficient. **Fig. 6. Relation of ZrB_2/ZrO_2 content and wear rate.**

Conclusions

$Al_2O_3/ZrB_2/ZrO_2$ composites were fabricated by hot pressing technology. The friction and wear behavior of this new material, coupled with cemented carbide ball in unlubricated conditions, were investigated. Experimental results showed that the friction coefficient values and wear rate of alumina matrix ceramic composites toughened by Zr-O-B compounds were lower than that of pure alumina. The wear rate of pure alumina was about 7×10^{-15} m^3/N·m while that of alumina matrix ceramic composites toughened by 20% Zr-O-B compounds was about 1.5×10^{-15} m^3/N·m. The mechanism responsible was explained as the formation of a lubricating film between the sliding couple, and the composition of this lubricating film was found to be ZrO_2 and B_2O_3. The generated lubricating film can decrease the friction coefficient of the composites, and makes the wear rate did not reach the theory value.

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