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Short communication

Sliding wear behaviour of Ca α-sialon ceramics at 600 °C in air

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Abstract

As an extension of a previous investigation on the wear behaviour of Ca α-sialon ceramics of differing microstructures at room temperature, wear testing was conducted at 600 °C in air to explore the effects of microstructure, contact pressure and sliding speed on the wear behaviour. Under all loading conditions from 1 MPa to 1 GPa, a constant high friction coefficient was observed and a severe wear process was dominant, in which the sliding contact induced cracks were observed in different microstructures. Wear particles were generated along the wear track, but no tribofilm was detected. Increasing the sliding speed from 10 to 23 cm/s was found to significantly increase wear rate. However, variations in microstructure had little impact. That is, large elongated-grained α-sialon exhibited only a slightly lower wear rate than fine equiaxed-grained α-sialon.

Keywords: α-sialon; Microstructure; Severe wear; Friction coefficient; Sliding speed

1. Introduction

α-Sialon ceramics have high hardness and are potential materials for abrasion-resistant applications. In recent years, considerable effort has been invested in the development of in-situ toughened α-sialon ceramics [1], and a typical case is the development of calcium α-sialons with elongated grains [2,3].

The room temperature sliding wear behaviour of Ca α-sialons has been investigated [4–6]. Results revealed that a large elongated-grained α-sialon had a higher mild-to-severe wear transition threshold than a fine equiaxed-grained material. Moreover, within the severe wear regime the large elongated-grained α-sialon exhibited a reduced wear rate, compared to the fine equiaxed-grained material, due to a greater resistance to crack extension arising from the coarser microstructure. Within the mild wear regime material removal for the large elongated-grained material was controlled by transgranular fracture, whereas grain pull-out prevailed in the fine equiaxed-grained material. Consequently, a greater wear rate was observed for the finer material. In addition, an increase in sliding speed caused a slight increase in wear rate for both microstructures, more evidently in the mild wear regime. Sliding wear models suggest that grain aspect ratio plays a more important role than grain diameter in the control of sliding wear behaviour [6].

Wear applications of α-sialon ceramics may involve high temperatures and oxidizing gaseous environments, where degradation of mechanical properties and chemical reactions may take place on the wear surface. Therefore, further work is required to examine the wear behaviour of α-sialons at elevated temperatures.

In this present work, unlubricated sliding wear tests were carried out at 600 °C in air, using a ball (SiC)-on-disc configuration, to investigate the effects of microstructure, contact pressure and sliding speed on the sliding wear behaviour of α-sialon ceramics. Additionally, this present study is an extension of a previous room temperature wear investigation of Ca α-sialon ceramics and will allow the effect of temperature on the wear behaviour to be assessed. The wear tracks and wear particles were examined using a focused ion beam (FIB) system and X-ray photoelectron spectroscopy (XPS) to identify the wear mechanisms of Ca α-sialons at high temperature.

2. Experimental procedure

Processing of fine equiaxed-grained (EQ) and large elongated-grained (EL) Ca α-sialon samples was described in detail in an earlier work [3]. The microstructural parameters and mechanical properties of each are listed in Table 1. The same

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Table 1
Microstructural and mechanical properties of α-sialon EQ and EL [3]

Sample identification	Average grain diameter [μm]	Aspect ratio	Density [g/cm^3]	H_V [GPa] (load = 98 N)	K_{IC} [MPa m$^{1/2}$] (load = 98 N)[a]	Young's modulus [GPa][b]
EQ	0.35	1.1	3.19	12.8 ± 0.5	3.7 ± 0.3	311.28
EL	0.70	7.2	3.21	12.0 ± 0.2	7.5 ± 0.3	305.88

[a] Obtained from Vickers indentation test.
[b] Obtained from nanoindentation test using a spherical tipped conical indenter (5 μm in radius).

procedure was used here for α-sialon disc specimen preparation as that used at room temperature [6].

Unlubricated sliding wear tests were performed on a ball-on-disc type high temperature tribometer (CSEM Instruments, Switzerland) at 600 °C (measured at the base of the specimen) in air. A 4.5 mm diameter SiC ball was used, which is the same as that used for the room temperature study in [6]. A series of non-stop tests (maximum sliding distance of 1 km) were run at a constant applied normal load of 5 N and at two sliding speeds of 10 and 23 cm/s, with a track radius of 4 mm. The friction coefficient was measured in real time by the tribometer.

After each sliding test, loose wear debris scattered on the worn disc were collected for chemical analysis (X-ray Photoelectron Spectroscopy, ESCALAB220i-XL, VG Scientific, UK). Subsequently, the sample surface was gold coated, without any surface cleaning, and examined using a focused ion beam (FIB) system (FEI xP200 focused ion beam miller, FEI Company, Portland, USA).

The normalized wear rate, w_n, and the apparent contact pressure between the SiC ball and the α-sialon disc, p, were calculated at successive distances according to the following equations:

$$w_n = \frac{2(V_2 - V_1)}{(l_2 - l_1)(A_1 + A_2)} \tag{1}$$

$$p = \frac{2P}{A_1 + A_2} \tag{2}$$

where V is the wear volume, l is the sliding distance, A is the apparent contact area calculated by the wear scar diameter of the ball, P is the normal load, the subscripts 1 and 2 represent measurements at successive distances. The wear volume is calculated as:

$$V = 2\pi R(S_{ave}) \tag{3}$$

where R is the sliding radius and S_{ave} is the average wear track cross-sectional area measured by a contact type profilometer (SURFTEST SV-600, Mitutoyo, Japan).

3. Results

The measured friction coefficients of both α-sialon samples tested at 600 °C in air were similar and in a range of 0.6–0.8 under both the 10 and 23 cm/s sliding speeds. The influence of both microstructure and sliding speed on wear rates of the two α-sialons during sliding tests at 600 °C is shown in Fig. 1. The wear rates are plotted as a function of apparent contact pressure and wear data at room temperature is given for comparison [6]. Firstly, it can be seen that the wear rates of EQ and EL at 600 °C are much higher than at room temperature for all apparent contact pressures. As the apparent contact pressure reduces, the wear rates of both α-sialon microstructures decrease slowly, but no wear transition can be distinguished. Secondly, the microstructure had only a small influence on the wear rate; EL has marginally greater wear resistance (i.e. slightly lower wear rate) than EQ. Thirdly, the wear rates of EQ and EL increased with increasing sliding speed, and this effect was more evident as the apparent contact pressure decreases. Measurements of wear scar diameter of the SiC ball at particular sliding distances revealed that the apparent contact pressure was the same for both microstructures as a function of sliding distance.

The wear tracks of both EQ and EL materials as a function of sliding distance for a speed of 10 cm/s were examined (Fig. 2). Significant material removal took place continuously on the sliding surfaces of both α-sialon materials. Fine wear debris particles were trapped in the wear tracks, and in general, the size of wear particles decreased as the sliding distance increased. There were no identifiable differences between the worn surfaces of the two samples at the same distance in terms of wear debris and surface cracking. The evolution of subsurface damage as the sliding distance increases was revealed by FIB milling and imaging. At high contact pressures (∼800 MPa), large subsurface cracks formed (Fig. 3(a)). As the contact pressure decreased (∼0.8 MPa), the size of cracks was observed to decrease (Fig. 3(b)). When the sliding speed was increased to 23 cm/s, the number and size of cracks increased and more wear debris appeared, as compared to the 10 cm/s sliding speed at

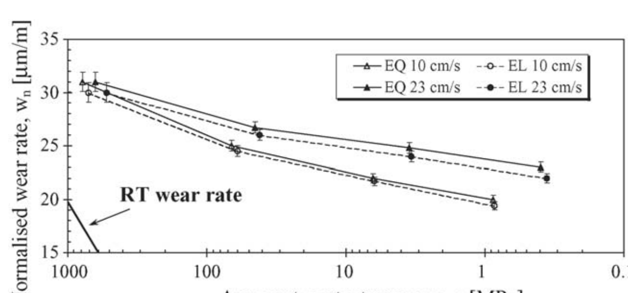

Fig. 1. Normalized wear rate, w_n, of EQ and EL vs. apparent contact pressure, p, at sliding speeds of 10 and 23 cm/s. Note that the line on the left corner shows the normalized wear rate measured for EQ at room temperature, 50 cm/s and 5 N as a function of the apparent contact pressure. This represents the maximum room temperature wear rate of the Ca α-sialon material studied by the authors [5,6].