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HIGH TEMPERATURE WEAR OF ADVANCED CERAMICS

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Introduction

It was initially hypothesized that advanced ceramics would exhibit favorable high temperature friction and wear properties because of their high hot hardness and low achievable surface roughness characteristics [1]. Further, localized asperity tip welding observed in metals does not occur in ceramics. More recent tribological studies of many nitride, carbide, oxide and composite ceramics, however, have revealed that ceramics often exhibit high friction and wear in non-lubricated, high temperature sliding contacts [2 to 5]. Table 1 summarizes measured friction and wear factor coefficients for a variety of ceramics from self mated ceramic pin-on-disk tests at temperatures from 25 to up to 1200 °C. Observed steady state friction coefficients range from about 0.5 to 1.0 or above. Wear factor coefficients are also very high and range from about 10^{-5} to 10^{-2} mm^3/N-m. By comparison, oil lubricated steel sliding results in friction coefficients of 0.1 or less and wear factors less than 10^{-9} mm^3/N-m.

Microscopic analyses of worn ceramic surfaces reveal two major modes of wear: brittle fracture and tribo-oxidative wear. High friction coefficients during sliding generate high tensile stresses in the wake of the contact area [6]. If sufficiently large flaws exist, cracks form, grow and ultimately lead to faceted wear debris formation (Figure 1). Brittle wear predominates at lower temperatures for all ceramics and at high temperatures brittle behavior is a common feature for oxide materials like alumina. Nitride and carbide containing ceramics sliding at high temperature in air form complex and often glassy oxide surface layers which are removed by the sliding counter-face revealing fresh, non-oxidized surfaces. These then oxidize resulting in an oxidative type wear process. The wear debris from these tests is often characterized by smeared oxide layers and sometimes even "rolled up" layered debris (Figure 2).

Table 1. Friction and wear summary for pin-on-disk sliding of ceramics

Pin /Disk Material, °C	Friction Coefficient	Average Wear Coefficient, mm^3/N-m	Wear Mode,** ref. no.
Al_2O_3 (25)	0.84	10^{-7}	M (3)
Al_2O_3 (1000)	0.50	10^{-7}	M (3)
SiC (25)	0.75	10^{-7}	M (3)
SiC (1000)	0.77	10^{-5}	O (3)
Si_3N_4 (25)	0.60	10^{-5}	M (2)
Si_3N_4 (1000)	0.70	10^{-2}	O (2)
*Al_2O_3-SiC_w (25)	0.74	10^{-7}	M (4)
Al_2O_3-SiC_w (1200)	0.58	10^{-6}	MO (4)
ZrO_2 (25)	0.68	10^{-4}	M (5)
ZrO_2 (800)	0.65	10^{-4}	M (5)

*Al_2O_3-SiC_w is alumina with 25 volume percent silicon carbide whiskers added.

**M = microfracture, O = oxide-layer removal, MO = microfracture-oxidation

Ceramics possess useful thermal, physical and chemical properties and can be used provided their shortcomings are accommodated. For instance, oil lubricated silicon nitride is successful in fuel injectors and hybrid ball bearings. As research efforts progress, advanced ceramics will find ever increasing applications in engineering and technology.

Fig. 1 TEM photomicrograph of faceted wear debris following room temperature sliding of an Al_2O_3-SiC_w whisker reinforced ceramic composite [4].

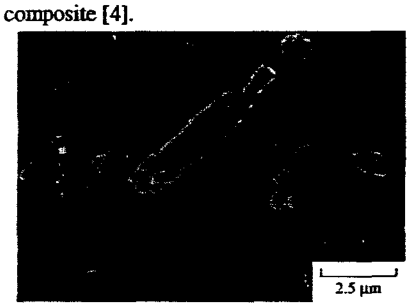

Fig. 2 Ceramic wear debris formed from oxide layer removal on Al_2O_3-SiC_w disk specimen following 1200 °C sliding in air [4].

References

[1] Kamo, R. and Bryzik, W.: "Solid Lubricants for an Adiabatic Engine," Lubrication Engineering, vol. 48, no. 10, pp. 809–815, 1992.

[2] Skopp, A., Woydt, M., and Habig, K.H.: "Unlubricated Sliding Friction and Wear of Various Si3N4 pairs between 22 and 1000 C," Tribology International, vol. 23, no. 3, pp. 189–199, June 1990.

[3] Wang, H., Kimurs, Y., and Okada, K.: "Sliding Friction and Wear of Ceramics at Elevated Temperatures up to 1000 C," Proceedings of the Japan International Tribology Conference, Nagoya, Japan, 1990, pp. 1389–1394.

[4] Jahanmir, S.: Friction and Wear of Ceramics, Marcel-Dekker, Inc., NY, pp. 225–259, 1994.

[5] Sliney, H.E. and DellaCorte, C.: "The Friction and Wear of Ceramic/Ceramic and Ceramic/Metal Combinations in Sliding Contact," Lubrication Engineering, vol. 50, no.7, pp. 571–576, 1993.

[6] Richerson, D.W., Lindberg, L.J., Carruthers, W.D., and Dahn, J.: "Contact Stress Effects in Si3N4 and SiC Interfaces," Ceramic Engineering Science Proceedings, vol. 2, pp. 578–588 (1981).