Water Lubrication of Ceramics: Mechanisms of Lubrication

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Abstract

Ceramics such as Al_2O_3, SiC and Si_3N_4 have been successfully lubricated by water under low speed (<0.23 ms^{-1}) and low load (<40 MPa mean contact pressure) conditions. The lubrication mechanism for these materials varies but a common thread is the role tribochemistry plays in these systems.

Water lubrication of Alumina

In the presence of water, we have observed [1] that friction coefficient can decrease by a factor of two (0.6 to 0.3) and the wear rate of alumina can drop by two orders of magnitude compared to dry sliding. Using careful analysis of the wear debris and surface chemical reactions of alumina, we proposed that the lubrication mechanism consisted of a combination of stress-induced phase transformation and reaction between water and the alumina surface to produce aluminum hydroxides which are layer lattice structures. These layer lattice structures perform as solid lubricants.

Water lubrication of Silicon-Based Ceramics

Silicon-based ceramics such as silicon nitride can be effectively lubricated by water under contact pressures up to 40 MPa and speeds as low as 0.12 ms^{-1} [2-4]. After a wear-in period, low friction coefficient (<0.01) can be achieved for average contact pressures of 40 MPa and lower.

Tomizawa & Fischer proposed a tribochemical dissolution mechanism to reduce surface roughness enabling the onset of hydrodynamic lubrication by water [2]. The chemical mechanism for such a process includes surface reaction between water and the surface to form silica which is then hydrolyzed to silicon hydroxide and dissolves in the water.

$$Si_3N_4 + 6H_2O \rightarrow 3SiO_2 + 4NH_3$$

$$SiO_2 + 2H_2O \rightarrow Si(OH)_4$$

In our experiments, we have observed effective lubrication under conditions where pure hydrodynamic contribution from water should not be sufficient, suggesting an additional lubrication mechanism is present. Xu and Kato [3] suggested that charged particles of colloidal silica provided the "hydrodynamic lift" observed. While we agree that water-Si reactions may produce surface and colloidal silica, we have observed very effective lubrication at pH 2 near the isolelectric point of silica where these charge interactions should be minimized; therefore, other lubrication mechanism may be present.

We propose that a substantial part of the lubrication mechanism for water-lubricated silicon-based materials involves the formation of surface silica gel films on the rubbing surfaces. Vigil et al. [5] looked at the surface of silica in the presence of water using the surface force apparatus and suggested the presence of an outer silica gel layer. In certain wear tests we have observed a smeared layer that has transferred to the upper and lower wear scar surfaces as the speed is reduced under load (Fig.1). Probing of the nature of this film manually and with a Triboscope revealed the soft, pliant nature of the film.

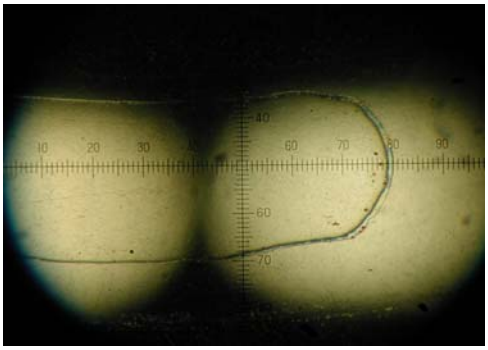

Fig. 1 Optical photograph of gel film on wear track.

Conclusions

Water-surface reactions can play a key role in the lubrication of ceramic materials. In the case of alumina, reaction, combined with phase transformation produces a solid-lubricating film in situ. In the case of silicon-based ceramics such as silicon nitride, we hypothesize that the key tribochemical reactions taking place not only polish the high spots on the surface asperities, but produce a soft hydrated silica gel layer in-situ. This soft gel layer fills small imperfections in the surface and provides a smooth, soft, protective film in the rubbing contact.

References

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