WEAR MODEL HYPOTHESIS FOR CARBON/CARBON COMPOSITE BRAKES

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Introduction

An initial hypothesis is presented for modeling the wear rate of carbon carbon composites in the low energy regime. Brittle behavior is assumed for carbon/carbon composites because of their retention of mechanical properties to very high temperatures. A friction film is not included explicitly in the model, but the validity of the model is primarily intended to cover the range of friction operation in which stable friction films are not normally observed.

Several key observations have been made which must be explained by any wear mechanism. These observations are:

- Highest wear rates occur at low energy conditions.
- Low energy dissipation condition wear surfaces show a scratched, low polish appearance.
- Medium energy dissipation wear surfaces show a high polish for low wear rate materials.
- Debris for low energy wear surfaces are larger in size than for medium or high energy conditions.
- Large scratches in the wear surface at high energy are very short in the otherwise polished surface.
- Wear polished surfaces show a thin amorphous carbon layer, even in the absence of an obvious wear film.

Taken together, these observations imply that larger debris particles are present at taxi conditions, and larger particles which break out at high energy appear to be quickly reduced to small particles, ultimately compacting into a wear film

Murdie and Wood [1] have classified different types of debris materials. They observe that under low energy conditions, debris and wear films consist of discrete particles larger than two microns. The size of these particles decreases as the energy of the stop increases.

Hutton, McEnaney and Crelling [2] find that under low energy conditions, significant modification of the carbon debris material occurs, as evidenced by the x-ray diffraction and density of the debris particles collected from ejected dust.

Karl-Heinz Zum Gahr [3] gives a discussion of wear mechanisms and microstructure. In dry three-body systems of inert materials, abrasion is most likely to be the active mechanism. Abrasion includes fracturing in brittle materials.

The microcracking of brittle materials occurs when the local stress on a structure exceeds the material or interface strength. The applied pressure at which the stress exceeds the strength is referred to as the critical pressure. While wear is known to occur below this critical pressure, its rate is very low compared to the rate observed above the critical pressure.

For three body wear, the abrading material acts as a load concentrator. Since fewer large particles can fit on a wear surface, fewer particles share the applied load. Thus fracturing of the surface occurs at lower applied loads for large abrading particles. This leads to the concept of a critical applied load which is particle size dependent and is given by: (adapted from Zum Gahr [3] eq. 5-58)

$$P_{crit} = \Phi \frac{\lambda K^2}{D^2 H}$$

Where

Φ = debris shape factor
λ = characteristic length between cracks
K = fracture toughness of the substrate material
D = debris particle diameter
H = hardness of the substrate material

The resulting 3 body wear depth per unit time is given by: (from Zum Gahr [3] eq. 5-59)

$$W = \Phi \frac{D^3 P^{\frac{3}{2}} H^{\frac{1}{2}}}{\lambda^2 K^2} \left[1 - e^{-\sqrt{P/P_{crit}}}\right]$$

The above relation predicts an increased wear rate at increased pressure for a given debris size. It also predicts a higher pressure required to achieve wear for a smaller debris size.

For a system where the debris particle is not significantly stronger than the surface, the debris size will not remain constant. In fact, one would expect that debris would break up to smaller particles until the local stress did not exceed its own strength. The process would continue until the critical pressure matches the applied pressure.

The wear rate obtained from reference 5 and presented above should also hold for the decrease in particle diameter of the abrading wear debris. Thus the rate expression for the decrease in diameter of the wear debris should be:

$$dD/dx = \Phi \frac{D^3 P^{3/2} H^{1/2}}{\lambda^2 K^2} \left[1 - e^{-\sqrt{P/P_{crit}}}\right].$$

This expression can be integrated numerically as a function of sliding distance in order to obtain an expression for the changing debris size with sliding distance. Figure 1 shows the effects of pressure on the decay of an initial unit particle size with sliding distance. The units are arbitrary. The actual values of pressure and distance will depend on materials properties such as hardness, toughness, and grain size.

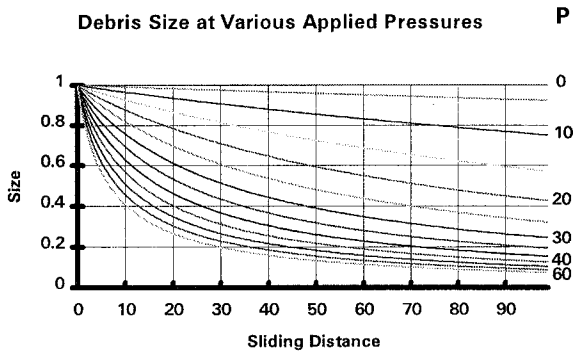

Figure 1: Plot of a series of curves showing the attrition of particle size with sliding distance for a range of pressures. Units are arbitrary.

It is assumed that the result is to produce a steady state size distribution whose mean size is a decreasing function of pressure. For the purposes of this model, the relative mean debris size vs pressure was taken to be that observed after a sliding distance of 100 units on Figure 1.

Now if the abrading particle diameter in Equation 2 is replaced by an equilibrium particle diameter that depends on the applied load according to Figure 1, then the decreasing diameter can drive the wear rate down. With a small equilibrium debris size at high pressure, the critical fracture pressure is increased, making the wear process less efficient. In addition, the (debris size)3 term in the expression of the wear rate can override the pressure term, resulting in a net decrease in wear rate with pressure. Figure 2 plots the wear rates at various pressures. The chart assumes that the debris size has reached a steady state value, and predicts the steady state wear rate at various pressures. The main prediction of the equilibrium wear rate case is that the wear rate will maximize at a low pressure, then decrease with increased pressure.

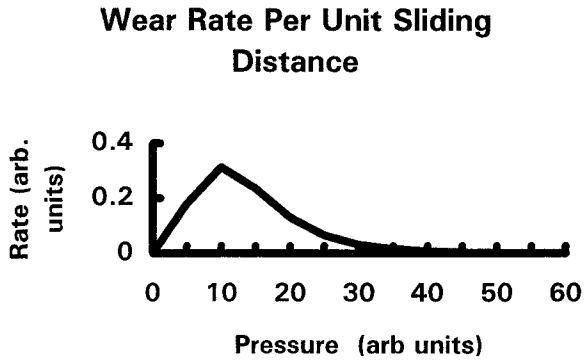

Figure 2. Wear rate per unit sliding distance vs pressure. Units are arbitrary. The plot is intended to show that a peak in wear rate is predicted from the elements of the model.

For Figure 2, an arbitrary set of materials constants have been used which allowed display of the trends of the wear rate with pressure.

Conclusions

The overall behavior of the wear rate equation can be tested by measuring the materials properties relevant to the equations for actual samples, and comparing their wear rate prediction ranking with actual wear tests. Confirmation of the materials effects would point to ways to improve wear performance. Lack of predictive ability would point to directions for model improvement.

References

1. N. Murdie and M. Wood, in Carbon *'96 (Ext. Abstr, Europeon Carbon Conference),* Newcatle upon Tyme, England, 1996. pp. 415-416.
2. T.J. Hutton, B McEnaney, and J. Crelling in *Carbon '96 (Ext Abstr. European Carbon Conference),* Newcastle upon Tyme, England, 1996. Pp. 417-418
3. Karl-Heinz Zum Gahr in *Microstructure and Wear of Materials, Tribology Series*, Vol. 10, Elsevier, 1987.