2012 STLE Annual Meeting & Exhibition
May 6-10, 2012
Renaissance Grand Hotel & America's Center
St. Louis, Missouri, USA

THERMOELECTRIC MEASUREMENTS OF SLIDING ASPERITY CONTACT FLASH TEMPERATURES

TRACK OR CATEGORY

Contact Mechanics

AUTHORS AND INSTITUTIONS

R. A. Erck, O. O. Ajayi, and G. R. Fenske, Energy Systems Division, Argonne National Laboratory, Argonne, IL 60439

INTRODUCTION

A knowledge of flash asperity heating of sliding surfaces is important for the understanding friction, wear, and the generation of chemical reaction films that may form in oil-lubricated systems. When two materials are brought together to form a sliding contact, friction and/or deformation at asperities causes a local and momentary increase in temperature at the contacting points. The surface temperature also important for understanding scuffing, which has been attributed to adiabatic shear instability under high loads and speeds [1]. Several predictive models have been published for dry [2] and lubricated sliding [3] under various conditions. A direct means of measuring surface flash temperature rise is by using a dissimilar material thermoelectric method. If the counterfaces are dissimilar materials that generate a thermoelectric voltage, the dynamic thermocouple method can be used to measure surface temperatures during sliding, and thus the temperature rise. This method has the advantage of good temperature calibration, but is not useful for the steel-steel sliding system. In addition, if multiple asperities at different temperatures are in contact, the measured value midway between these temperatures. Only rarely will a single asperity be making contact. Nevertheless, this technique can be useful.
Sliding couples that have been reported on include constantan-steel [3], alumel-steel [4], Ni-brass and others [5]. In this work, type K thermocouple materials are used.

EXPERIMENT AND RESULTS

Sliding flash temperatures were measured using a unidirectional (block on ring) tribometer that incorporated a 35-mm diameter alumel ring that was slid against a stationary chromel block; both block and ring were 6.35 mm wide. Data were obtained at rates up to 100 kHz, and an air motor was used to rotate the ring to minimize electrical interference.

Fig. 1. shows a graph of data from two 20N load tests using a polished ring immersed in either an unadditized polyalphaolefin basestock (2 cP at 100C), or a synthetic 70W90 gear oil. The instantaneous asperity temperature signal is erratic, as junctions are created and broken during rotation of the ring against the block. Fig. 1 shows that for low sliding speeds and low coefficient of friction, maximum asperity heating does not exceed a few tens of degrees, with occasional spikes to a few hundred C thought to be due to a single or few asperities in contact. But the combination of a large coefficient of friction and high sliding speed produces temperature rises up to 800C. The apparent periodicity is thought to be due to irregularities that develop on the rotating ring as wear begins to occur.

Fig. 2 is a histogram of the data from Fig. 1b between 0.5 and 0.7s that shows that for sliding speeds near 4 m/s and a coefficient of friction near 0.6, where the sliding surfaces are poorly separated by fluid, there is a broad distribution of temperature centered around 400°C. The spike at 100°C is thought to be due to a bulk rise of temperature in near-surface region that contributes to the overall "background" temperature. Other histograms obtained for sliding under steady state conditions typical of good boundary lubrication regime (μ~0.1) show a more Gaussian type of distribution.

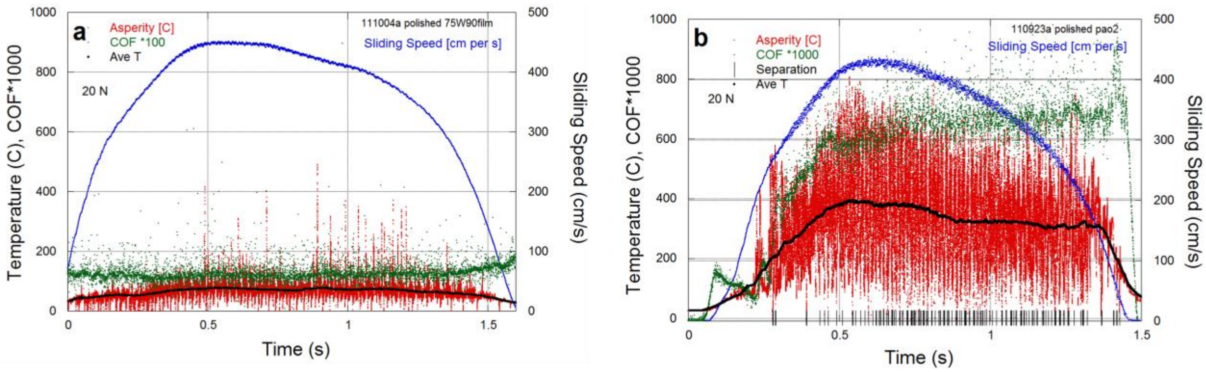

Fig. 1 Graphs of instantaneous asperity contact temperature, average asperity contact temperature, coefficient of friction, and sliding speed as a function of time for a 20 N test. 1a) 75w90 oil. 1b) PAO2 base stock oil.

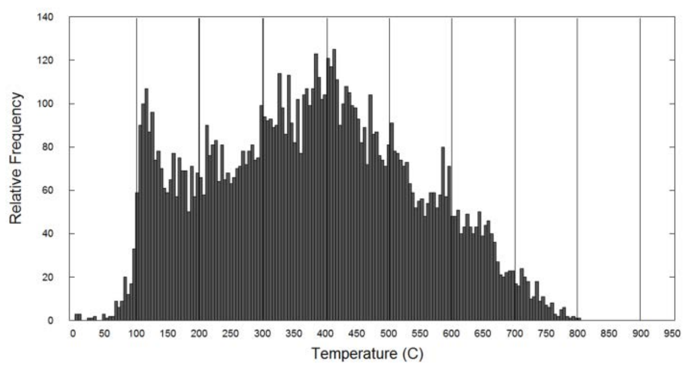

Fig. 2. Histogram of data from Fig. 1b showing relative frequency of occurrence of temperatures, for sliding between 0.5 and 0.7s

Scuffing may be described as a sudden catastrophic failure of lubricated sliding contact, and is usually accompanied by a large sudden rise in friction, contact temperature, and noise. Scuffing is a problem in heavily loaded contacts systems, and gives little or no warning when it is about to occur, and thus it is an issue for highly loaded steel contacts. This phenomenon has been studied and found to occur in other systems, such as zirconia, when deformation mechanisms to relive friction stress are unable to operate [6].

Fig. 3 shows the behavior of a test at constant 50 N load in which an apparent low friction and temperature steady state running seems to be attained, that then suffers catastrophic surface damage at 17 s into the test. The subsequent drop in COF and asperity temperature may be due to an activation of the oil additives, but the friction and temperature never return to their original values.

For light loads, irregularities in the surface may cause the sliding surfaces to be momentarily separated, which may need to be taken into account when modeling frictional heating.

The graphs that have been presented appear to show continuous contact during the sliding. To determine whether this is true, it is possible to impose a high impedance bias voltage between the surfaces and lack of electrical continuity can be sensed.

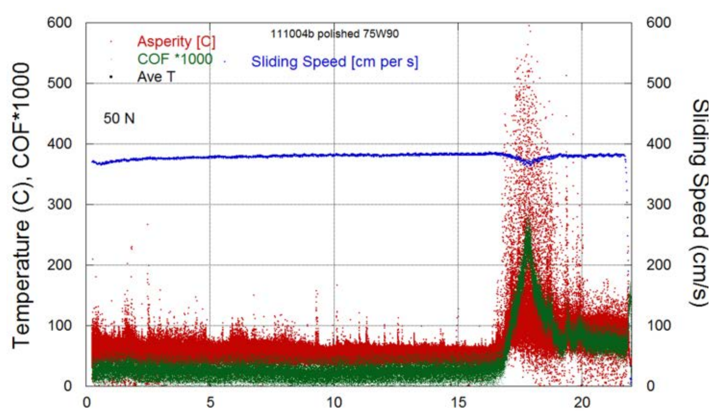

Fig. 3. Graph of scuffing event that occured after sliding at 50 N load.

In Fig. 1b, the small vertical lines on the abscissa denote instances of separation between the sliding surfaces. For light loads the sliding surfaces may not be in contact continuously, especially if the surfaces are rough. This is particular evident in Fig. 4 where substantial loss of contact occurred.

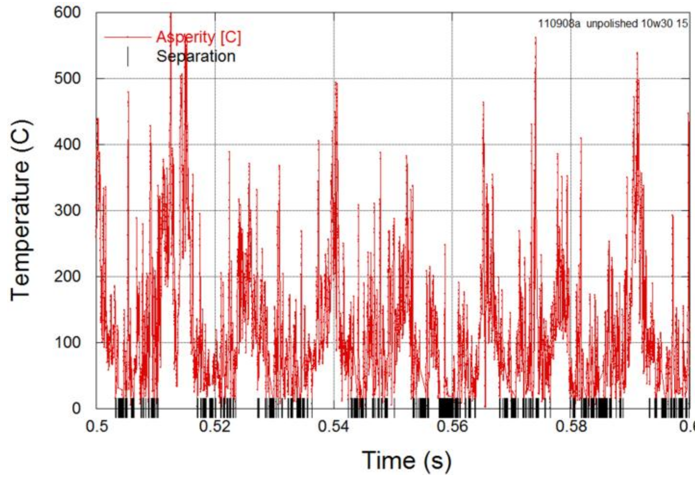

Fig. 4 Detail of graph of asperity temperature for test using 15 N load at 430 cm/s producing surface separation.

SUMMARY

When two metals are brought together to form a sliding contact, friction and/or deformation at asperities causes a local and momentary increase in temperature at the contacting points. A dynamic thermocouple method was used to measure surface temperature during sliding. In this research, sliding flash temperatures were measured under unidirectional (block on ring) and reciprocating sliding conditions with type-K counterface materials. For oil-lubricated sliding up to 0.4 m/s with a light load, peak and average temperatures were on the order of 100°C and 50°C, respectively. For higher load scuffing conditions, large increases in the coefficient of friction, from 0.15 to 0.6, were accompanied by large jumps in temperature, from room temperature to a peak of 800°C, although average temperatures did not typically exceed 250°C during scuffing. From the data obtained it was possible to determine that average asperity temperature was nearly independent of applied load for steady-state sliding. Experimental average temperature rise was a stronger function of sliding speed than parabolic, but was not less than linear.

ACKNOWLEDGMENTS

This work was supported by the US Department of Energy, Office of Vehicle Technologies, under Contract No. DE-AC02-06CH11357 by UChicago Argonne, LLC

REFERENCES

[1] Ajayi, O. O., Lorenzo-Martin, C., Erck, R. A., and Fenske, G. R., "Scuffing Mechanism of Near-Surface Material During Lubricated Severe Sliding Contact," *Wear,* **271** (2011) pp. 1750-1753.

[2] Ashby, M. F., Abulawi, J., and Kong, H. S, "Temperature Maps for Frictional Heating in Dry Sliding," *Tribol Trans.,* **34**, (1991), 4, pp. 577-587.

[3] Bowden, F. P., and Ridler, K. E. W., "Physical Properties of Surfaces. III. The Surface Temperature of Sliding Metals The Temperature of Lubricated Surfaces," *Proc. R. Soc. Lond*. A 1936, **154**, pp. 640-656

[4] Shen, J-H., Ettles, C. M., and Scarton, H. A., "The Analysis of Thermoelectric Signals in Metallic Sliding," *ASME Trans.*, **111**, Jan. 1989, pp. 114-120,

[5] Holm, R., "Calculation of the Temperature Development in a Contact Heated in the Contact Surface, and Application to the Problem of the Temperature Rise in a Sliding Contact," *J. Appl. Phys*., **19**, 1948, pp. 361-366.

[6] Lorenzo-Martin, C., Ajayi, O. O., Singh, D., and Routbort, J. L., "Evaluation of Scuffing Behavior of Single-Crystal Zirconia Ceramic Materials," *Wear,* **263** (2007), pp. 872-877.

KEYWORDS

asperity, friction, frictional heating thermoelectric, thermocouple