SURFACE TEMPERATURE MEASUREMENTS OF CARBON/CARBON COMPOSITE FRICTION MATERIALS DURING DYNAMOMETER TESTS

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Introduction

The interface temperature of friction surfaces is of considerable importance in the evaluation of friction performance of carbon/carbon composite brake materials. Since temperature is a fundamental driver in many materials properties, it is advantageous to know the instantaneous surface temperature during braking action to help deduce its affect on friction coefficients.

This paper reports the use of a quartz fiber optic probe system which was installed on a ring-on-ring brake dynamometer to obtain routine analysis of brake surface temperatures during tests of carbon/carbon brake materials. In addition, a finite element model of the friction material under heat load is used to assess thermal flow in the system.

Experimental

Initial spectral measurements were made to determine whether the optical system resulted in a true black-body radiation profile which could be sampled by a two-color optical pyrometer. Spectral measurements were made with a quartz fiber optic probe inserted from the back of the stationary test member to the friction face. Analysis of the profiles indicated that the emission was very close to black-body, and that further measurements could reliably use a two color pyrometer.

Subsequent measurements were made with an Accufiber four channel , two color pyrometer system. This system was capable of measurements at 0.1 second intervals for all four channels. The detector was optimized to measure temperatures in the 800-3000 deg C range, and was shown capable of measurements from 600 deg C. Four channels of data were obtained by placing the four probes from the inside diameter to the outside diameter of the ring sample.

Three materials were selected for tests based on their thermal conductivity perpendicular to the surface. The materials tested had room temperature thermal conductivities which ranged from 5 W/(mK) to 80 W/(mK). Two of the materials were molded from resin preimpregnated carbon cloth or fiber tow, carbonized, graphetized, then densified to 1.7 g/cm^2 or higher using natural gas CVI of carbon. One of the materials was constructed from needled carbon fiber mats, then densified using natural gas CVI of carbon. Dynamometer samples were constructed as split rings of composite cut from larger samples. The split rings had an interface area at full contact of 50.75 cm^2. The total sample weight varied between 180 g and 220 g depending on the composite density. The materials were tested at initial surface speeds of 15.96 m/s, 21.3 m/s, and 23.9 m/s at constant interface pressures of $7.79\text{x}10^5$ N/m^2, $1.18\text{x}10^6$ N/m^2, and $1.578\text{x}10^6$ N/m^2, with stored flywheel energies of 157 kJ, 279 kJ, and 353 kJ, respectively. All tests were conducted to the full stop condition.

Results and Discussion

Figures 1-3 show examples of the temperature vs. time data generated during these tests. Large differences existed in the four probes of a single sample, presumably due to uneven pressure on the friction surface interface, or due to thermal imbalances discussed later. Examples are chosen from the hottest observed regions. Surface temperatures for the lowest energy stop for the sample with the largest thermal conductivity never reached high enough values to be recorded by the optical system used. For that test, we show the temperature recorded by a thermocouple located close to the surface as a lower bound to the surface temperature. As expected, the lowest thermal conductivity material reached the highest surface temperature at each test condition.

Figure 1: Normal Landing Test

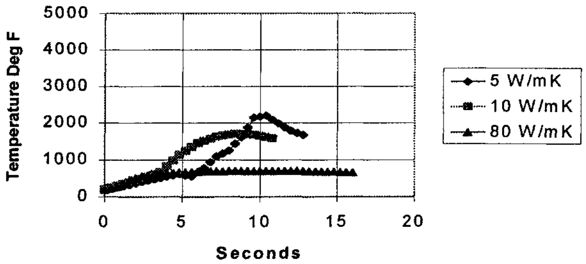


Figure 2: Overload Landing Test

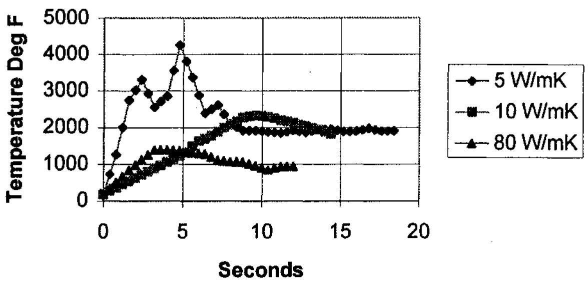
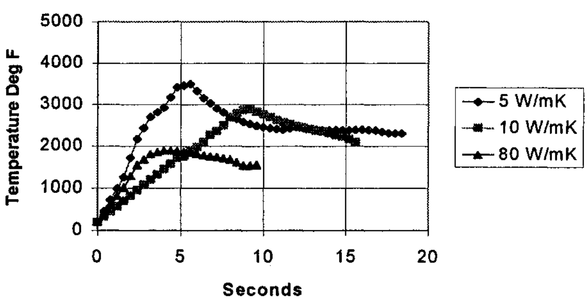


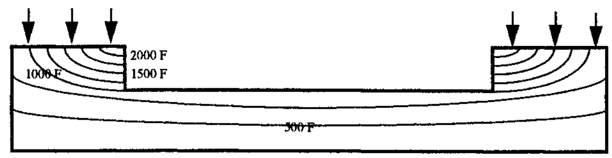
Figure 3: RTO Test



.In order to shed light on the thermal gradients and energy flow in this test geometry, a finite element model of the particular geometry used was constructed. The model included both radiative and convective heat transfer from the carbon to itself and the surrounding medium. The model was restricted to a constant heat input rate of 50 W/cm^2 on the friction surface, rather than a time varying input rate as is true in the actual tests. The model was evaluated at a time corresponding roughly to the time required to reach a peak in the experimental surface temperature measurement.

The temperature contours generated by the model indicate that there should a significant gradient in the surface temperature across the face of the test sample, with the highest temperature reached on the inside diameter of the friction surface. This is clearly due to significant radiative heat losses from the outer edge of the friction sample. In the model, the thermal conductivity of the sample was assumed isotropic. In reality, the low thermal conductivity samples usually exhibit a significantly higher thermal conductivity in the friction plane than perpendicular to that plane. This would cause even more heat loss to occur in that transverse direction.

Figure 4: Simulated Thermal Gradients



During the tests, it was clear that there were several thermal imbalances other than the inner to outer imbalance indicated by the finite element model. Large thermal "flashes", particularly in the lowest thermal conductivity material, were observed both visually as well as recorded in the thermal data. In Figure 2, for example, the large thermal excursions at 2.5 and 5 seconds into the test are direct evidence of such events. These are most likely due to so called "hot spots" which are thought to be caused by runaway heating of spots whose heating causes expansion, more load carying of the region, and thus more heating.

It should also be noted that there are lags in the thermal response recorded with the pyrometer. This is most likely due to the load (and thus the heat) being caried by a region of the sample not within the "track" of the optical fiber during the early part of the test for some of the recordings.

Conclusions

Significant differences are often found in the measured friction behavior in reduced scale tests of aircraft brake materials. While care is taken to try to recreate test conditions which match in the two systems, the inherent physical differences often lead to non-scaleable parameters. The results of the tests reported here indicate that the surface temperatures reached in reduced scale tests at scaled energy conditions may be significantly lower than those in equivalent large scale tests due to heat loss mechanisms which differ significantly in the two tests. The results point to design modifications of the reduced scale tests which should help bring the test more in line with those of full scale tests. In addition, the fiber optic probe system used was demonstrated to give reliable temperature measurements which should be of use in monitoring the behavior of the test materials.